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THE UNIVERSITY OF ALBERTA

BEHAVIOURAL AND PHYSIOLOGICAL RESPONSES OF FEEDLOT CATTLE (*BOS TAURUS*) TO WINTER CONDITIONS

by

© HAROLD GONYOU

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

IN

Animal Physiology

DEPARTMENT OF ANIMAL SCIENCE

EDMONTON, ALBERTA

FALL, 1977

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled .....
..Behavioural.and.physiological.responses.of.feedlot.
..cattle.(Bos.taurus).to.winter.conditions.....
submitted by .Harold.Gonyou.....
in partial fulfilment of the requirements for the degree of Master of Science.

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.....

.....

Date ..June.3,.1977.

ABSTRACT

In the first of three experiments, 24 growing steers, fed individually at feeding levels ranging from maintenance to twice maintenance, were housed through the winter in either a heated barn or in an open lot. Each steer was fed at a constant level throughout the 166 day period. Growth rate and feed conversion were lower in the outside steers and in those on low feeding levels. The outdoor steers had higher plasma concentrations of thyroxine (T_4) and triiodothyronine (T_3) and a higher T_3/T_4 ratio than did the inside steers. Hair coat depth was greater on the steers fed maintenance rations as opposed to those with higher intakes. Rectal temperatures decreased slightly during cold weather. All of the outdoor steers were observed shivering at some time during the experiment. The steers could endure colder temperatures without shivering as winter progressed. Respiration frequencies were highest for the steers on high levels of feed intake and for inside steers. Steers fed at a maintenance level increased their respiratory frequencies to a lesser extent (as ambient temperatures increased.) than did those on higher levels of intake The outside steers spent more time ruminating and lying and groomed less on cold days as compared to warm. The steers consumed more of their bedding material on cold days but no differences in shavings intake were present between feed levels. The digestibility of the ration decreased 0.29% per C^{o} decrease in ambient temperature.

In a second experiment water consumption of 199 bulls on ad libitum feeding was measured. Water consumption was directly related to body weight and mean daily temperature of the environment. Water consumption was greater after the concentrate/roughage ratio of the feed was increased during the experiment than before.

In the final experiment four steers were exposed in environmental chambers to temperatures of 20, 0, and -20 C in September and December. During exposure to 0 and -20 C the time spent ruminating increased whereas the time spent lying decreased. The frequency of reticular contractions was greater during rumination and increased progressively with decreasing exposure temperatures. Respiration frequency decreased during exposure to the colder temperatures and in December as compared to September during exposure to -20 C. The cattle had higher respiratory frequencies in December than in September when exposed to 20 C.

The results are discussed in regards to their importance to cattle exposed to cold conditions.

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INTRODUCTION

The Canadian climate, and that in other temperate or arctic zone countries, is characterized by a definite winter period which may involve severely cold temperatures during some years and in some areas. For example, the average January temperature in Edmonton, Alberta in 1970 was -28 C. Although some animal production systems, such as sheep farming, can function on a yearly basis in which the growth and finishing of the product occurs primarily in the summer, this is not true of the cattle industry. Cattle require nearly two years to reach market weight and even under the best of systems must encounter at least one winter.

Man has provided himself with temperature controlled dwellings and insulative clothing to protect himself from the effects of cold temperatures. Management practices for poultry and swine generally provide heated or at least well insulated buildings for these animals. However, the cost of adequate buildings can be a limiting factor in the profitability of an enterprise. The question remains, particularly in respect to feeder cattle, does the increase in production due to providing housing adequately compensates for the extra cost involved.

Research in the area of cattle production under winter conditions have involved not only growth or production parameters but also the physiological effects of cold weather. A knowledge of the physiological

responses to cold environments should not only provide a better understanding of the problems associated with cold exposure but also greater possibilities of solving these problems.

A similar arguement can be made for the study of the animals behavioural responses to winter conditions. Although in discussion of the effects of cold on cattle many authors state that behavioural responses may modify the effects, however, few researchers have studied these behavioural changes.

In the present study on the effects of cold temperatures on cattle not only are the production traits of the animals measured but also physiological and behavioural responses. It is hoped that the results of these experiments, in addition to results of previous and future studies, will be of benefit in establishing more efficient management systems.

LITERATURE REVIEW

It is generally accepted that cold conditions, such as those occuring in winter throughout much of Canada, adversely affect beef production. Recent studies have shown the quantitative effects of cold on the efficiency of production. Results vary between studies due to the multitude of factors which influence the effects of cold.

1. Effects of Cold Environments on Efficiency of Production

Webster, Chlumecky and Young (1970) studied three groups of heifers over the winter. The control group was exposed to 20 C throughout. An outdoor (sheltered) group was provided with shelter while the third group (without) was kept outside without shelter. Grain intake was held constant but hay was fed ad libitum. The sheltered group had the highest feed consumption and also the greatest weight gain. The control group ate considerably less feed but had gains almost equal to the sheltered group. The without group ate nearly as much as the sheltered group but gained much less. This experiment was of limited size (total of 12 cattle) but involved severe temperatures (average January temperature was -28 C). It did however indicate a drop in efficiency due to cold and a further drop when shelter was not provided.

In another experiment, Webster, Hicks and Hays (1969) found that sheep kept inside during the winter consumed the same amount of feed as unsheltered outdoor animals yet gained 62% more in body weight. Sheep in environmental chambers exposed to temperatures designed to simulate the outdoor

cold stress, consumed more feed yet still did not gain as much as the indoor group. Thus, decreased efficiency is seen in full fleeced sheep, a species considered to be extremely cold hardy.

Hidiroglou and Lessard (1971), working in northern Ontario, wintered steers outside in a fenced area or inside an unheated barn. The cattle outside encountered colder temperatures than the inside group. Feed consumption was the same, yet the outside animals gained 30% less over a period of 168 days. The inside animals may also have been under the stress of high humidity which has been shown, in association with cold temperatures, to decrease milk yield in dairy cattle (Williams and Bell, 1964). Effects of winter housing on weight gain similar to those shown by the Ontario workers have been shown by Self et al. (1963) and Bennett and O'Mary (1965).

The experiments described above each involved only 1 season during 1 year. Since the effects of winter would be expected to vary from year to year, long term studies, compiling data from many cattle fed during different seasons, need to be considered.

One such study, involving the evaluation of the California net energy system was reported by Knox and Handley (1973). Data for a period of 20 months obtained from northern Colorado feedlots involving over 95,000 steers and heifers was used. Estimated gain was calculated from feed consumption records. During the winter months the predicted gains were up

to 15% above the observed. Using the same formula for predicting of gain, the summer cattle gained up to 35% more than predicted. Mean monthly effective temperatures, considering wind, moisture, and temperature, ranged from - 23 to 10 C. Feed efficiency was lowered considerably by the winter environment.

Seven years of monthly feedlot performance records collected at Saskatoon, Saskatchewan, were analysed by Milligan and Christison (1974). A total of 1,970 steers were involved in the study. The cattle, housed outside, were protected by a windbreak and some had overhead shelter. Statistically significant regressions of daily weight gain and feed/gain ratio on temperature were obtained (0.014 kg/day/10 C^{o} and -.67 feed/gain/10 C^{o} respectively). Cattle fed over periods which included the coldest months of the year required an average of 220 kg extra feed and 27 more days to reach market weight than did cattle fed during the other 9 months.

2. Effects of Cold Environments on Metabolic Rate

An important concept in environmental studies is thermoneutrality. Mount (1974) defines the zone of thermoneutrality as "the range of environmental temperatures within which the metabolic rate is minimum and constant". There are limitations to this definition, as Mount points out, due to interactions of other environmental factors. The lower limit of this zone is referred to as the lower critical temperature. At temperatures below this critical

point metabolic rate increases to balance the heat loss to the environment. Efficiency is reduced as more of the energy intake goes to maintaining the animal rather than to production.

Webster (1970) estimated the lower critical temperature of feeder cattle in still air to be -31 to -38 C. Calves and cows had higher lower critical temperatures. Using this data alone one would predict that there would be little effect of winter on feedlot performance in most agricultural regions of Canada. In the same paper however, Webster points out that wind and precipitation could raise the lower critical temperature of feeder cattle to -9 C. This estimate was made using a previous study by Webster and Park (1967) involving sheep exposed in environmental chambers to wind and to a water spray. Application of the results to cattle, although useful, cannot be expected to be entirely accurate due to the different type of hair coat. A lower critical temperature of -9 C would not account for the decrease in efficiency seen in some of the studies cited above.

One factor that might contribute to a reduced efficiency in a cold environment is an elevation in resting heat production. Webster et al. (1969) found that resting heat production in a thermoneutral environment (8 C) was higher in sheep that had been kept outdoors or in cold rooms than in warm acclimated sheep. This was explained as acclimatization, but the underlying physiological mechanisms

have not been explained. The prolonged exposure to cold induced a persistant elevation in resting metabolic rate, even when the animal was returned to a warmer environment. Young (1973) reported a similar pattern in cattle. Cows kept outside during the winter had higher metabolic rates at temperatures of 30, 0, and -30 C than did cattle kept inside in a controlled warm room. In a second experiment two cows were alternated, for periods of 8 weeks, between -12 and 20 C. Following prolonged cold exposure metabolic rates were greater at both -12 and 20 C than after similar periods of warm exposure.

Not all studies are consistent with these findings. Webster et al. (1970) did not find significantly higher resting metabolic rates in cattle exposed outdoors during a severe winter when compared to an indoor control group. A sheltered outdoor group did have an increased metabolic rate but part of this could be attributed to a greater feed consumption.

Changes in an animal's metabolism due to a prior exposure to a particular environment is a type of acclimatization. In a series of experiments Slee (1970, 1972, 1974) attempted to define and evaluate some aspects of acclimatization to cold. Three basic treatments were used. Sheep were exposed for periods of 1 to 2 weeks to either 30 C, to a chronic, moderate cold (8 C) or to 30 C interrupted daily by a short (less than 2 hr) exposure to acute cold (-20 C). Two types of metabolic responses were observed.

Resting metabolic rate (as indicated by heart rate) increased at thermoneutral temperature after exposure to cold. Sheep previously exposed to cold also exhibited an increased resistance to body cooling when exposed to a long period (2 to 8 hr) of acute cold. This was believed due to enhanced peak metabolic rate capability.

Retention of the characteristics of acclimatization varied depending on the type of previous cold exposure. In sheep exposed to chronic cold the increased resistance to body cooling began to decrease after 2 weeks in a thermoneutral environment. Those acclimatized by exposure to acute cold did not show a decrease in this parameter until after 2 weeks at warm temperatures, but after 8 weeks at a thermoneutral temperature acclimatization had disappeared. In a group exposed to a combination of both chronic cold and acute cold shocks the increased capacity to resist body cooling during acute cold showed little decrease even after 8 weeks. In contrast to these long retention periods for increased resistance to body cooling, the increased resting metabolic rate was retained for only 8 days in a thermoneutral environment regardless of the cold acclimatization procedure. Young (1975) found that the resting metabolic rate of beef cows exposed to chronic low temperatures returned to normal by approximately 2 weeks after returning the animal to a warm environment.

Acclimatization affects an animal's response to cold climates. The increase in resting metabolic rate would

effectively decrease the lower critical temperature, however, at temperatures above the lower critical temperature the increased resting metabolic rate would adversely affect production efficiency. The lower critical temperature of cattle exposed to winter conditions was found to be -18 C (Webster et al., 1970). Controls during this experiment, kept at 20 C, had lower critical temperatures of -2 to 7 C. Even with acclimatization the outside cattle were exposed to subcritical temperatures during much of the trial.

3. Effects of Cold Environments on Digestion

Research has also shown more specific influences of temperature on animal processes. One of these areas of study has been digestive physiology. As ambient temperature decreases the digestibility of feed has been shown to decrease in sheep (Graham et al., 1959; Graham, 1964; Westra and Christopherson, 1976; Ames and Brink, 1977). A similar pattern has also been reported in cattle by Blaxter and Wainman (1961), and Christopherson (1976). Warren et al. (1974) and Westra and Christopherson (1976) have reported a decreased mean retention time of the ingesta in the alimentary tract during cold exposure. The latter authors also reported greater frequency of reticular contractions in cold exposed animals. These two parameters may be related to the decreased digestibility. Although Kennedy, Christopherson and Milligan (1976) reported some compensating and potentially beneficial changes in protein digestion during exposure to cold, the net effect of cold

on digestion tends to contribute to a reduced energetic efficiency of production.

4. Effects of Cold Environments on Hair Coat

The hair coat or pelage of an animal serves as a layer of insulation between the environment and the temperature sensitive tissues of the body. Hair coat depth has been shown to increase in cattle during long term cold exposure by Webster et al. (1970). In these cattle, kept outside during the winter, the growth rate of hair was similar to that of animals housed indoors. The increased coat depth in the outdoor animals was attributed to decreased shedding. A similar trial using sheep indicated no changes in wool growth or insulation due to cold exposure (Webster et al., 1969). Indeed, Graham et al. (1959) found less wool growth in closely clipped sheep when exposed to 13 C as opposed to 28 C, although this experiment was of short duration.

5. Effects of Cold Environments on Blood Parameters

The environmental temperature has been shown to influence several blood parameters. Bailey (1964) observed higher packed cell volumes after exposing his sheep to colder temperatures. Hidiroglou and Lessard (1971) found higher blood haemoglobin levels in cattle wintered outside. Elevated packed cell volumes and reduced eosinophil counts were observed in cold exposed sheep by Mears and Groves (1969). Exposure to cold resulted in significantly higher thyroxine and triiodothyronine concentrations in sheep

(Westra and Christopherson, 1976), and higher rates of thyroxine turnover in cattle (Yousef, Kibler and Johnson, 1965). However, the role of thyroid hormones in cold adaptation is not yet clear according to Webster (1974).

6. Interactions Between Feeding Level and Response to Cold

Similar effects to those of cold have also been observed when feed intake has been increased. Heat production increases as feeding level increases (Blaxter, 1967). Sheep on a high feeding level had a greater rate of heat production, even after 6 days of fasting, than did sheep on a low feeding level. Increased heat production, due to increased feed consumption, also resulted in a lowering of the lower critical temperature. Below the critical temperature of the high intake group the heat loss from animals on high and low levels of feeding was similar, and related to the thermal gradient between the animal and the environment.

A similar relationship between heat loss, temperature and feeding levels has also been reported in pigs. Close, Mount and Start (1971) found that at a temperature of 7 C heat loss by groups of piglets was not related to feed level. At warmer temperatures (12, 20, and 30 C) heat losses were related directly to feeding level.

Digestibility of feed by ruminants decreases as intake increases (Blaxter and Wainman, 1961). MacDonald, Edwards and Greenhalgh (1966) state that an increase in feed consumption of 50 to 100 % will reduce digestibility by 1 to 3 %. This is attributed to a faster rate of passage of

the ingesta which these authors suggest results in decreased digestion due to a shorter period of exposure of the material to digestive enzymes.

Balch (1961) states that "the most consistent influence on the rate of passage has been the level of feeding". Balch and Campling (1964) showed that retention time of the ingesta in the alimentary tract decreases as daily feed intake increases in cows. The qualitative effects of increasing the feed intake are much the same as the effects of cold on retention time and digestibility (mentioned in an earlier section) although the mechanisms may not be the same.

7. Behaviour and the Cold Environment

Extreme environmental temperatures, whether hot or cold, are stressful to animals. One means of reducing these streeses is the use of appropriate behaviour. Hafez (1969) suggests that animals in the cold will modify their behaviour in an attempt to increase heat production, increase radiation gain, and decrease heat loss. This could be accomplished by such activities as increased feed consumption, seeking direct sunlight, decreasing respiration and increasing flexure (decreasing exposed body surface).

More specific behavioural patterns have also been reported. Piglets tend to huddle together in temperatures below 30 C. This reduces the oxygen consumption per kilogram of body weight when compared to non-huddled pigs.

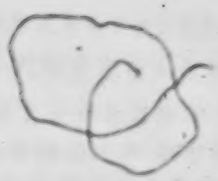
The importance of huddling becomes more pronounced as temperature decreases (Mount, 1960).

Pigs kept outside avoided drafty areas in a study by Ingram and Legge (1970). These pigs did not seek out areas of high radiant heat, although in environmental chambers pigs quickly learn to turn on radiant heat lamps during cold (Ingram, 1975). Pigs will also turn off fans to avoid drafts in laboratory experiments. The importance of huddling, avoiding drafts or seeking radiant heat has not been established in cattle.

Bailey, Hironaka and Slen (1962) found a relationship between water consumption and temperature. Sheep kept in environmental chambers at -12 C drank less water than when the temperature was 15 C. Young (1975), working with two beef cows, found similar decreases in water consumption in the cold. Water consumption was extremely low for the first 3 days after transfer to a lower environmental temperature. Severely reduced water intake resulted in a weight decrease for several days. However, MacDonald and Bell (1958a) found water intake of cows increased slightly in cold weather.

Other effects of cold temperatures on behaviour that have been reported include reduced grazing time, increased standing (Malechek and Smith, 1976), reduced respiration frequency and shivering during extreme cold (Young, 1975). Further studies on behaviour may reveal the role that certain activities play in the animals attempt to maintain homeothermy with a minimum expenditure of energy.

Interrelationships between behaviour and observed physiological responses to cold may be discovered which would increase our understanding of the animal. Management methods which allow animals to exercise their thermoregulatory behaviour may decrease the loss of efficiency associated with cold environments.



EXPERIMENTS CONDUCTED AT THE UNIVERSITY OF ALBERTA

Three experiments were conducted to investigate the behavioural adaptations and associated physiological responses of cattle to cold environments.

Experimental Procedures and Materials

1. Experiment I

This experiment involved a period of 166 days commencing on October 15, 1975 and terminating on March 28, 1976. A fire on January 20 involved some of the animals and necessitated major changes at that point including the removal of 2 pens of cattle from the trial.

a. The animals

Twenty-eight yearling steers of predominately Hereford breeding were individually indentified with ear tags. The animals were weighed and allotted to experimental treatments in such a way as to provide as uniform groups as possible according to body weight. All animals were fed a maintenance diet for a 15 day observation period prior to the imposition of treatments. During this period one animal which showed signs of poor temperament was exchanged with an animal of approximately equal weight in the initial slaughter group. Initial weights averaged 345 kg and ranged from 313 to 395 kg.

b. Experimental treatments and rations

A group of 4 steers was slaughtered on the first day of the experiment to provide initial carcass data. The remaining 24 steers were fed at one of 4 levels of intake for the remainder of the trial. The lowest level of feed intake was estimated to be the average maintenace requirement of the animals. This was calculated assuming a requirement of 586 KJ D.E./$W_{kg}^{0.75}$ daily. The group receiving the greatest amount of feed was fed twice the estimated maintenance requirement. The intermediate groups received approximately 1.3 and 1.6 times maintenance.

The cattle were housed in 6 pens with each pen containing 1 animal from each feed group. Four of these pens were outside with exposure to natural conditions. The remaining two pens were inside an environmentally controlled barn.

The ration components and feeding levels are listed in appendix tables 1, 2 and 3. Due to the loss of a quantity of alfalfa pellets in the fire a different supply was used beginning on January 30 and continuing to the end of the experiment.

c. Housing

The 4 pens of outside cattle were initially kept at the Ellerslie Bull Testing Station in pens providing 8 sq. m./steer. A roof covered 65% of each pen and protection from the wind was provided by nearby structures with the exception of winds from the west south west and the east

north east. Individual feeding stalls were provided in each pen. Water was available from heated water bowls.

The 2 pens of inside cattle were housed in the south wing of the Metabolic Unit of the University of Alberta Edmonton Research Station. The pens provided 5.1 sq. m./ animal. Water was available from automatic water bowls. Feeding took place in individual pens (3.6 sq. m.) adjacent to the main pens. The barn was heated to provide an environment with a temperature of approximately 19 C. All cattle, inside and out, were bedded with similar softwood shavings. Bedding material was replaced or added whenever necessary to ensure clean dry bedding areas.

On day 99 of the experiment a fire at the Ellerslie station destroyed the facilities housing the outside groups. The cattle in the pen closest to the centre of the blaze suffered noticeably singed hair coats. Because of possible effects of the fire the cattle from two pens most severely exposed were slaughtered at that time. The animals from the remaining two pens were moved to new facilities at the Edmonton Research Station. These pens provided 80 sq. m./ animal, with a roofed area, wind protection and watering facilities similar to the initial pens. Wood shavings were again used as bedding.

d. Daily treatment of cattle

Water bowls were sealed each day from 800 h until after the steers were fed. At 1300 h the cattle were individually weighed and returned to their pens. At this point the

cattle were tied into individual feeding stalls and fed the entire daily ration at approximately 1330 h. When feeding was complete at 1530 h the cattle were given access to the entire pen. Any feed not consumed was weighed and recorded.

Interruptions occurred occasionally that prevented strict adherance to this schedule. General cleaning of the pens at Ellerslie prevented weighing on two days during the experiment. The fire resulted in several days of adjustment when measurements were not made.

e. Meteorlogical measurements

A meteorlogical station was established within 20 m of the outside pens. Maximum and minimum temperatures and average wind speed, recorded at a height of 1 m, during the previous 24 hr were noted at 800 h daily. Wet and dry bulb temperatures were also recorded at this time when temperatures were above freezing. The temperature at 1300 h was recorded daily. When the animals were moved to the University Farm this data was obtained from the meteorlogical station of the environmental lab, approximately 200 m from the animals. On occasions when data were not collected it was derived from meteorlogical reports of the Edmonton International Airport located approximately 25 km from the sites.

Maximum and minimum temperatures over the previous 24 hr in the barn housing the indoor animals were recorded at 800 h each day. Temperature at 1300 h was also recorded. Measurements were taken in the centre of the wing of the

barn in which the animals were housed.

f. Production evaluation

The average daily gain of each steer was derived from the rectilinear regressions of body weight on days. Total weight gain was defined as the difference between the expected body weight values determined by the regression for days 1 and 166. Feed efficiency was determined for the total gain (kg gain/kg feed). In order to maintain simplicity in the analysis values of the 8 steers slaughtered in January were not included in the analysis.

g. Behavioural observations

Behavioural observations were made on the outside animals on 9 occasions between January 9 and March 5. During each period the observer stationed himself outside of the pen in full view of the cattle and remained quiet during the observations. The cattle were accustomed to the presence of people in these areas and paid little attention to the observer.

Each pen was observed for 10 minutes between 830 and 930 h. Records were kept of individual animals. The posture of each animal (standing or lying) and whether or not it was ruminating was recorded at 1 minute intervals. "Grooming" behaviour was recorded as individual events. These included a steer licking itself or another steer, scratching itself with a foot, and rubbing the pen wall or fencing. Bunting was also recorded. The site of this

grooming on the body was recorded as the head or neck region, the trunk of the body, the legs, or the rump of the animal. Ambient temperature at the time of observation was recorded.

In determining the time spent lying and time ruminating an animal was considered to have been engaged in the activity for the entire minute if at the end of that minute it was observed to be lying or ruminating. Grooming was further divided into wet grooming (licking) and dry grooming (all other grooming) for analysis. In analysis of the data temperature at the time of observation and the time after sunrise were included as sources of variation. The time after sunrise was defined as the time from sunrise to the average time of observation (900 h). For the inside animals, if sunrise was after the lights of the barn were turned on in the morning, the time of the lighting of the barn was defined as sunrise.

h. Blood collection and analysis

Blood samples were collected twice during the experiment. On February 27 the cattle were confined to a squeeze to obtain skin samples for another study. At this time 20 ml of jugular blood were collected in heparinized containers. Duplicate determinations of haematocrit, red blood cell numbers, and white blood cell counts were made. A single determination of haemoglobin was performed using a Spencer haemoglobinometer. The blood was then centrifuged and plasma removed and frozen for later analysis.

On March 25 blood samples were obtained from the tail of each animal into heparinized containers. Duplicate haematocrits were performed. The remaining sample was centrifuged and the plasma frozen for later analysis.

All samples were thawed and determinations of thyroxine (T_4) and the thyopac index, relating T_4 concentrations and the uptake of triiodothyronine (T_3), were made. A Thyopac-4[1] kit was used for the assay of T_4 while a Thyopac-3[1] kit was used for the T_3 uptake test and calculation of the thyopac index. Samples were refrozen until a later date for determination of T_3 concentrations. This was determined using a RIA-Mat[2] circulating T_3 I^{125} diagnostic kit. The ratio of T_3 concentration to the T_4 concentration was calculated for each sample. Determinations of I^{125} activities were performed using either a Nuclear-Chicago well counter[3] (DS5 probe) or a Beckman Biogamma[4].

i. Feed and fecal collection and analysis

Feces were collected on 3 consecutive days each

1. Purchased from Amersham/Searle Corporation, Arlington Heights, Illinois, U.S.A.
2. Purchased from Mallinckrodt, Inc., St. Louis, Mo., U.S.A.
3. Purchased from Nuclear-Chicago Corporation, Des Plaines, Illinois, U.S.A.
4. Purchased from Beckman Instruments, Inc., Fullerton, Ca., U.S.A.

week from each animal. Grab samples were obtained from the rectum while the animals were eating. If no sample could be obtained from the rectum but a recent defecation from that animal was available it was collected with care being taken to avoid contamination with foreign material. Feces were always collected between 1300 and 1500 h. Samples were sealed in plastic bags, labelled, and frozen for later analysis. Feed samples were collected periodically and handled similarly. A sample of the shavings used as bedding was also stored.

On 5 occasions during the experiment chromic oxide (Cr_2O_3) was fed to the animals as a digestibility marker. Pellets containing 20% Cr_2O_3, 40% of the grain mixture and 40% ground alfalfa on a dry weight basis were prepared. Each animal was fed 50 grams of these pellets with their feed daily for periods of 2 weeks. The final period involved 3 weeks of daily administration of pellets. The allotment of pellets was mixed into each animals feed by hand and was consumed with no apparent refusals.

During the last week of each Cr_2O_3 feeding period the inside animals were confined to their feeding stalls for the entire time. Access to water was provided by watering bowls between pens. Daily routine was identical to other periods with the exception of the confinement

and the absence of any bedding. During the confinement periods a 7 day total collection of feces was conducted. Feces were removed from the floor twice each day, weighed, and mixed on a daily basis. A 5% sample by weight was retained from each days collection and at the end of the 7 day period a composite of the daily samples was made for each animal. After mixing, a subsample of the composite was analysed for dry matter content.

The feed and fecal samples were removed from their storage bags and weighed. After drying in a forced air oven at 65 C for 72 hours the samples were reweighed and dry matter content calculated. Feces samples were ground in a Waring blender until they were of a powder consistency. Composite samples were made using equal amounts of each days dried feces. These were mixed in a Waring blender and rebagged for chemical analysis. Feed samples and shavings were ground in a Christy-Morris mill[1] and stored in plastic bags.

Feces which contained no Cr_2O_3 and from weeks after Cr_2O_3 had been fed for a minimum of 7 days were analysed with the feed and shavings samples. The acid insoluble ash (AIA) content of the samples was determined using the 2 N HCl method of Van Keulen and Young (1977). Lignin analysis was performed on the same material using a modified method of Van Soest (1963) as given in Appendix 1. Feed and feces samples were analysed for

1. Model No. 8, Chelmsford, England

chromium using a modified technique of Czarnocki, Sibbald and Evans (1961) as described in Appendix 2. Only samples from animals on the high or the low feeding levels and which were involved over the entire experimental period were analysed.

Estimates of shavings consumption were made using ratio techniques involving AIA and lignin or Cr_2O_3 and lignin. Digestibility estimates were then made using the ratio of AIA or Cr_2O_3 in the feed and feces. The equations used for these calculations are developed in Appendix 3. A digestibility value of .05 was assumed for the bedding material in all calculations. In vitro analysis by Millett et al. (1970) indicates this to be a maximum value for untreated softwoods.

In analysis of the shavings intake and digestibility data the values were related to the mean of the daily minimum and maximum temperatures recorded during the 7 days prior to the last day of fecal collection.

j. Shivering, rectal temperatures and respiration frequencies

During fecal collection observations were made on the occurence of shivering. An animal was considered to be shivering if muscle trembling was observed in the hip while the animal was otherwise standing quietly. A maximum observation time of 30 seconds was used. Immediately afterwards rectal temperatures were obtained using a telethermometer approximately every second

week throughout the experiment.

Respiration frequencies were determined prior to daily weighing by counting the flank movements or the puffs of expired vapour during 30 second periods. These values were recorded at approximately 2 week intervals throughout the experiment.

k. Hair coat measurements

Measurements of hair coat depth were taken on March 25. A rule was inserted through the hair coat to the skin and a measurement was taken at a tangent to the coat surface. Both free-standing depth and the depth of the hair when compressed with fingers were recorded. Eight sites were measured on each animal. The sites chosen were 15 cm from the midline of the animal over the scapula, the last rib, and the hook bone on either side of the animal, and on the midline over the mid-rib and the mid-lumbar region.

l. Statistical analysis

Data was analysed by analysis of variance using method 1 of Overall and Klett (1972). Regressions were calculated by a least squares linear model. Frequency of shivering was compared using the χ^2 method. All other multiple means were compared using Duncan's multiple means comparison test.

2. Experiment II

This experiment, designed to study the water consumption of cattle in winter, took place between December 22, 1975, and April 10, 1976.

a. The animals and management

The experimental animals were 199 bulls involved in a performance testing program at the Ellerslie Bull Testing Station. The cattle were housed in four open front barns, each of which contained 10 pens. Each pen contained five bulls with the exception of one which held four bulls throughout the experiment and a second which held five cattle until March 21 when one was removed. The bulls averaged 274 kg at the beginning of the testing program on November 26, 307 kg when water consumption data collection began, and 448 kg at the end of the trial.

The bulls were fed ad libitum a concentrate mixture and chopped hay. Prior to February 18 this was fed in a 40:60 ratio and thereafter in a 50:50 ratio. The formulation of the concentrate mixture is given in appendix table 4. Water was continuously available from heated water bowls.

b. Data collection

Water consumption for each barn was determined using water meters[1] installed in the water supply lines. Readings were taken each morning at 800 h. Average water consumption

1. Neptune meters, manufactered by Trient

per animal was calculated. Data for a number of days was not included in analysis due to management practices which may have interferred with water consumption. Only data for 86 days when the bulls had had access to water without interruption for the previous 48 hours was used.

Maximum and minimum temperatures over the previous 24 hours were recorded at 800 h daily. The mean of these temperatures was used as the effective temperature for analysis.

The bulls were weighed at intervals of 28 days throughout the water intake trial. Mean animal weight for each barn was calculated for the days the cattle were not weighed by regression analysis and water intake was expressed as consumption per unit of body weight.

c. Statistical analysis

Analysis of variance and least squares linear regression were used in the analysis of the data obtained.

3. Experiment III

This experiment was conducted between September and December 1976 at the University of Alberta Edmonton Research Station. Two series of trials, one in September and one in December, were performed.

a) The animals and management

Four mature rumen fistulated steers weighing between 439 and 535 kg were used in the study. They were housed, with the exception of the actual trial periods, in an

outside lot with an open front barn as shelter. For 3 weeks prior to each series of trials the steers were individually fed long stemmed hay at a rate of 1.5% of their body weight per day. Body weight was determined at the beginning of the experiment in September. Feeding took place between 1300 and 1600 h each day. Water was available at all times except during feeding. Body weights and feeding levels are given in appendix table 5.

b. The trials

During each series of trials the steers were individually exposed to temperatures of -20, 0 and 20 C in a random order (Table 1). The animal was tied in a stanchion in an environmental chamber at 1700 h and remained there until 1200 h the following day. No feed or water was available during this time. The lights were turned off overnight from 2000 h to 800 h. After removal from the chamber the steer was returned to the outside lot and fed as usual. The animal was not returned for a subsequent trial until at least the following day. During each trial the steers were subjected to various measurements.

Reticulum motility was monitored between 900 and 1200 h during each exposure. This was measured by a pressure sensing device consisting of a weighted, fluid filled balloon supported by a copper tube inserted through the rumen fistula and placed in the reticulum. A pressure transducer outside the chamber was connected to the device

Table 1. Schedule of temperature exposures for steers (experiment 3).

STEER	SEPTEMBER			DECEMBER		
	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 1	TRIAL 2	TRIAL 3
217	20	-20	0	0	-20	20
335	0	20	-20	0	20	-20
337	20	0	-20	20	-20	0
609	20	-20	0	-20	0	20

by tygon tubing. Changes in the reticular pressure were recorded on a continuous chart by a Sanborn Physiological Recorder[1]. The animals posture (whether lying or standing) could be determined by the base line of this recording.

Respiration frequency was determined by observations of the flank movements at 15 minute intervals during the 3 hr recording period. This was accomplished without entering the room by making observations through a small window in the chamber.

During the September trials the occurence of rumination was noted at 5 minute intervals during the recording period and recorded on the reticulum motility chart. Breaks in the pattern of reticular movements were used to more precisely determine the beginning or the end of the rumination periods. In December the jaw movements of each steer were recorded on a kymograph by a tambour connected to a pneumograph around the muzzle of the animal. These records were made between 1900 and 2200 h in addition to the 3 hr recording period in the morning. Rumination records were correlated with reticular motility records to calculate the frequency of biphasic reticular contractions during rumination, in the absence of rumination, and average frequency.

Rectal temperatures were obtained using a telethermometer before and after the morning recording period. The two measurements were averaged for analysis. Occurances of shivering and the associated stance of the animal were

1. Manufactured by Hewlett Packard, Pallo Alto, Calif.

recorded.

c. Statistical analysis

Analysis of variance was used to determine significant effects. Differences between means were determined by Duncan's multiple means test. Reticular motility during rumination and non-rumination was compared using a paired t-test (Alder and Roessler, 1968).

Results

Experiment I

All animals were consuming their daily ration within two weeks of the beginning of the experiment. No health problems were encountered which necessitated treatment although one steer in an outside pen had a rectal temperature of 41 C on one occasion. No other signs of illness were apparent at that time. The cattle which were retained on the experiment did not appear to suffer any adverse effects from the fire. During the 7 day periods of total fecal collection the inside animals lost on average 8.4 kg in body weight. This weight loss was soon regained the following week and did not appear to affect overall gain. The mean weekly temperatures encountered during the experiment are given in appendix table 6.

Animal Performance

The mean values for average daily gain, total gain, and gain per unit of feed are given in table 2. The average daily gain and total gain of the outside animals were significantly less ($P<.05$) than for the inside animals. Feeding level also significantly influenced growth ($P<.05$) with the animals receiving larger amounts of feed gaining more rapidly. The interactions of housing and feed level on these parameters were not significant.

The gain/feed ratios were higher for the inside animals than for the outside ($P<.05$). The steers on the lower

Table 2. Performance data of steers (experiment 1)

PARAMETER	HOUSING	FEEDING LEVEL (TIMES MAINTENANCE) 1.0	1.3	1.6	2.0	MEANS (H)	MEAN ±S.E.
Average daily gain (kg/day)	outside	.023	.344	.520	.665	$.388^{d}$	
	inside	.382	.516	.719	1.086	$.676^{e}$	
	mean	$.202^{c}$	$.429^{bc}$	$.619^{ab}$	$.875^{a}$		.53 ±.078
Total gain (kg)	outside	8	57	86	110	64^{d}	
	inside	63	86	119	180	112^{e}	
	mean	34^{c}	71^{bc}	103^{ab}	145^{a}		88 ±13.0
Gain/feed (kg/kg)	outside	.006	.060	.074	.079	$.055^{a}$	
	inside	.089	.090	.102	.129	$.102^{b}$	
	mean	$.047^{a}$	$.075^{ab}$	$.088^{ab}$	$.104^{b}$		.08 ±.012

a,b,c means with different letters differ significantly ($P<.05$)

d,e means with different letters differ significantly ($P<.01$)

H housing

feed levels had lower gain/feed ratios which approached significance ($P<.10$).

Hair depth

The results of the hair depth measurements are given in table 3. No significant differences were found in the compressed hair depths for any of the treatments. Free standing depths were significantly greater ($P<.05$) for the animals on lower than for those on the higher feed levels. Hair depths also differed significantly ($P<0.05$) between measurement sites.

Blood values

The mean values of the blood parameters are given in tables 4a and 4b. There were no significant differences between treatments for the haemoglobin and white blood cell values. Red blood cell numbers were greater in the outside animals than in the inside cattle but only at a probability level of 10 %. Packed cell volumes were higher in February than in March, ($P<.01$) and the month by housing interaction indicates that the values dropped more in the outside animals than in the inside ($P<.01$).

All thyroid hormone values were greater in the outside ($P<.05$ for thyopac index, T_3 and T_3/T_4, $P<.01$ for T_4) compared to the inside animals. Significant differences between months were also found for T_4, thyopac index ($P<.05$) and T_3/T_4 ratio ($P<.01$). Values were consistently higher in February than March. Feed level differences were not

Table 3. Hair depth measurements (cm) on steers in March (experiment 1)

HAIR CONDITION	HOUSING	FEEDING LEVEL (TIMES MAINTENANCE) 1.0	1.3	1.6	2.0	MEAN (H)	GRAND MEAN ± S.E.
Compressed	outside	0.55	0.48	0.51	0.44	0.50	
	inside	0.32	0.41	0.36	0.29	0.35	
	mean	0.43	0.45	0.43	0.37		0.42 ±.014
Free Standing	outside	2.16	1.84	1.79	1.57	1.84	
	inside	1.56	1.14	1.09	0.73	1.13	
	mean	1.86^{a}	1.49^{ab}	1.44^{b}	1.15^{b}		1.49 ±0.11

a,b means with different letters differ significantly ($P<.05$)

H housing

Table 4a. Analysis of blood from steers (experiment 1)

PARAMETER	HOUSING	MONTH	FEED LEVEL (TIMES MAINTENANCE) 1.0	1.3	1.6	2.0	MEAN (MH)	MEAN (H)	GRAND MEAN ± S.E.
Haemo-globin (%)	outside	Feb.	17.5	14.3	17.0	16.6		16.35	
	inside		16.8	14.6	15.4	14.8		15.38	
	mean		17.1	14.4	16.2	15.7			15.86 ±0.39
White Cell count (1000/mm^3)	outside	Feb.	6.4	7.7	9.2	8.5		8.10	
	inside		9.8	9.0	11.2	8.8		9.74	
	mean		8.1	8.4	10.2	8.7			8.84 ±0.48
Red Blood Cells (10^6/mm3)	outside	Feb.	7.5	8.3	6.6	6.1		7.14	
	inside		6.5	6.3	5.8	5.5		6.04	
	mean		7.0	7.3	6.2	5.8			6.59 ±0.20
Packed Cell Volume (%)	outside	Feb.	48.0	38.9	44.6	46.5	44.5^a		
		Mar.	40.0	35.3	37.8	33.8	36.7^c		
		mean	44.0	37.1	41.2	40.2		40.6^e	
	inside	Feb.	41.0	38.0	42.3	39.3	40.2^b		
		Mar.	36.0	36.5	35.5	33.8	35.5^d		
		mean	38.5	37.3	38.9	36.6		37.9^f	
	mean		41.3	37.2	40.1	38.4			39.3 ±0.05

a,b,c,d means with different letters differ significantly ($P<.05$)

e,f means with different letters differ significantly ($P<.01$)

(MH) month by housing (H) housing

Table 4b. Analysis of blood from steers (experiment 1)

PARAMETER	HOUSING	MONTH	FEED LEVEL (TIMES MAINTENANCE) 1.0	1.3	1.6	2.0	MEAN (MH)	MEAN (H)	GRAND MEAN ±S.E.
Thyroxine (μg/100ml)	outside	Feb.	13.7	9.3	8.3	5.1	8.4		
		Mar.	6.4	4.6	5.5	5.9	5.6		
		mean	8.9	7.0	6.9	5.5		6.9[c]	
	inside	Feb.	6.8	7.7	7.6	8.1	7.6		
		Mar.	4.8	5.3	4.3	5.2	4.9		
		mean	5.8	6.5	5.9	6.6		6.3[d]	
	mean		7.1	6.7	6.4	6.1			6.6 ±0.45
Free Thyopac index	outside	Feb.	11.0	8.6	7.4	5.3	7.7		
		Mar.	5.0	4.2	4.6	5.2	4.8		
		mean	7.0	6.4	6.0	5.3		6.1[a]	
	inside	Feb.	6.0	6.4	6.0	6.6	6.3		
		Mar.	4.0	4.4	3.3	4.8	4.1		
		mean	5.0	5.4	4.7	5.7		5.2[b]	
	mean		5.9	5.9	5.3	5.5			5.6 ±0.39
Triiodothyronine (ng/100ml)	outside	Feb.	47	94	98	71	77		
		Mar.	75	99	94	148	104		
		mean	61	96	96	109		91[a]	
	inside	Feb.	77	66	95	35	68		
		Mar.	69	72	97	67	76		
		mean	73	69	96	51		72[b]	
	mean		67	83	96	80			81.4 ±5.5
T_3/T_4 (ng/μg)	outside	Feb.	1.0	10.9	12.0	21.0	12.6		
		Mar.	12.0	21.8	17.5	25.7	19.2		
		mean	8.3	16.4	14.7	23.4		16.2[a]	
	inside	Feb.	11.3	8.8	12.4	3.4	9.0		
		Mar.	14.9	14.6	23.0	12.9	16.3		
		mean	13.1	11.7	17.7	8.1		12.6[b]	
	Mean		11.0	14.0	16.2	15.7			14.3 ±1.4

a,b means with different letters differ significantly (P<.05)

c,d means with different letters differ significantly (P<.01)

(MH) month X housing (H) housing

significant.

Shivering, rectal temperature, and respiration rate

Shivering was first observed between November 28 and December 2 when the ambient temperature dropped to -9 C. It was not observed again until January 6, 7 and 8 when temperatures reached -39 C. Between these two periods temperatures were as low as -25 C during the observation periods. Shivering did not occur after January even during exposure to temperatures of -30 C. Although only cattle in the lowest feed level group were observed shivering in November, shivering was noted in cattle from all feed level groups in January. Severe shivering, associated with an arched back and a closed stance involving marked adduction of the limbs, seemed to occur more frequently in the low feed level groups, however, quantitative measurements of shivering intensity were not made. The occurence of shivering did not differ significantly between feed levels with 17, 10, 10 and 7 occurences being noted for feed levels 1.0, 1.3, 1.6 and 2.0 times maintenance respectively.

Rectal temperatures averaged 38.81 C with a standard deviation of $\pm$0.31 C. Average values of 38.89 and 38.75 C were obtained for outside and inside cattle respectively. In analysis of rectal temperatures from both inside and outside groups there was a significant ($P<.05$) temperature by housing interaction. When the data from the outside animals was analysed separately a significant regression of

rectal temperature on ambient temperature was found ($P<.01$). For each 10 C^{o} fall in temperature the animals rectal temperatures fell 0.14 C^{o}. The correlation coefficient for the regression was 0.37. No significant effect on rectal temperatures could be attributed to the feeding levels.

Respiration frequencies of the steers ranged from 6 to 54 respirations/minute. The temperature by housing and temperature by feed by housing interactions were significant when both housing groups were included in the analysis ($P<.01$). Within the outside animals feeding level was a significant source of variation ($P<.05$) with average respiration frequencies of 11.3, 15.0, 20.4 and 18.0 for feeding levels of 1.0, 1.3, 1.6 and 2.0 times maintenance respectively. Temperature and the temperature by feed interaction were also significant ($P<.01$) for the outside steers as shown in figure 1.

Estimates of shavings intake and digestibility

Mean values of shavings intake and digestibility estimates are given in table 5 and 6 respectively.

Estimates of shavings intake by a single steer ranged from -0.29 to 3.50 kg/day. The analysis of variance indicated that estimates of shavings intake were not significantly affected by housing, feed levels, or the method of determination. Estimates of shavings intake were significantly lower ($P<.01$) when shavings were temporarily unavailable than when animals had access to the material. The interaction

FIGURE 1. RELATIONSHIPS OF RESPIRATORY FREQUENCY, FEED LEVELS (TIMES MAINTENANCE) AND TEMPERATURE FOR STEERS (EXPERIMENT 1).

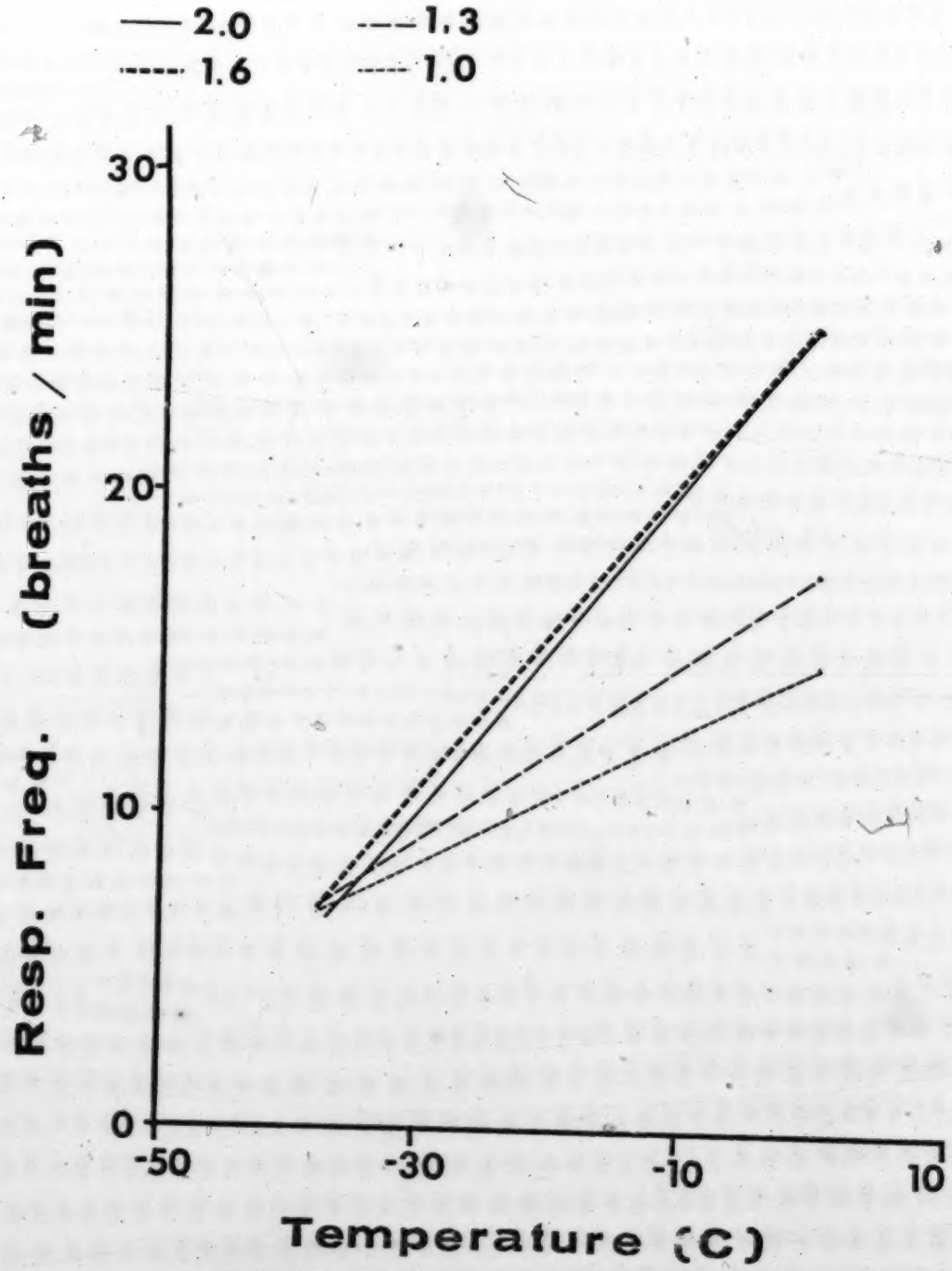


Table 5. Estimated shavings intake (kg/day/steer) by feedlot steers (experiment 1)

METHOD	HOUSING	FEED LEVEL (TIMES MAINTENANCE) 1		2		MEAN (H)	GRAND MEAN ± S.E.
AIA	outside	1.08	(20)[1]	0.98	(20)	1.03	
	inside	1.57	(10)	1.07	(10)	1.32	
		0.65	(10)[2]	0.49	(10)[2]	0.57	
	mean	1.10		0.88			0.99 ±.083
Cr_2O_3	outside	1.28	(12)	1.24	(12)	1.26	
	inside	2.00	(2)	1.62	(2)	1.81	
		0.44	(10)[2]	0.55	(10)[2]	0.50	
	mean	0.99		0.98			0.99 ±.088
mean (marker techniques)	outside	1.16		1.08		1.12	
	inside	1.64		1.16		1.40	
		0.55[2]		0.53[2]		0.54	
	mean	1.06		0.92			0.99 ±.062

H housing
1. ( ) number of observations
2. animals did not have access to shavings
AIA acid insoluble
Cr_2O_3 chromiun oxide

Table 6. Estimates of digestibility (DM %) by feedlot steers (experiment 1)

METHOD	HOUSING	FEED LEVEL (TIMES MAINTENANCE) 1	2	MEAN (H)	GRAND MEAN ± S.E.
AIA	outside	68.4 (20)[1]	66.5 (20)	67.5	
	inside	67.2 (20)	64.7 (20)	65.9	
	mean	67.8 (20)	65.6 (20)		66.6 ±0.67
Cr_2O_3	outside	66.8 (12)	64.0 (12)	65.4	
	inside	69.2 (12)	64.8 (12)	67.0	
	mean	68.0	64.4		66.2 ±1.31
mean (marker techniques)	outside	67.8	65.5	66.7	
	inside	68.0	64.7	66.4	
	mean	67.9	65.1		66.4 ±0.51
Total Collection	inside	61.6 (10)	68.6 (10)		65.1 ±1.82

H housing

1. ( ) number of observations

AIA acid insoluble

Cr_2O_3 chromiun oxide

between method and housing was significant ($P<.05$) with the Cr_2O_3 method producing higher estimates in the outside animals.

The effect of temperature on estimated shavings consumption was not significant when all other factors were held constant. There was a significant temperature by method interaction ($P<.01$). The estimates of shavings intake by the AIA method for the outside cattle were inversely related to temperature ($P<.05$). For each C^o decrease in temperature, shavings intake increased 0.06 kg/day in these animals. On the other hand, the relationship of shavings intake estimated by the Cr_2O_3 method and temperature was not significant.

No significant effects of feeding level on digestibility were obtained in the analysis of the total collection data. Digestibilities determined by the two marker methods were not significantly different although the interaction of method with housing was significant ($P<.01$). The differences in estimation of shavings intake by the two methods was highly correlated ($r= 0.95$) with the subsequent differences in digestibility estimates.

The analysis of variance for digestibility indicated that the housing systems were not significantly different with the outside animals having a mean digestibility of 66.7 as compared to 66.4% in the inside steers. The difference in digestibility due to feeding levels was not statistically significant.

When adjustments were made for the effects of housing,

pen, feed, and the method of determination, there was a significant ($P<.01$) relationship between digestibility and temperature. For each C^{o} drop in temperature there was a .29 % decrease in digestiblity. There was no interaction of temperature and feed level on digestibility. The interaction of temperature and method was significant ($P<.01$) with the AIA estimates changing more with temperature than the Cr_2O_3. Estimates of both methods were positively related to temperature.

Rumination, lying, and grooming

Regression equations for rumination, lying and grooming on temperature are given in table 7. Time spent ruminating did not vary significantly between feeding levels or between housing treatments. The average time spent ruminating was 41.1 and 30.9 % for the inside and outside steers respectively. However, the outside steers ruminated significantly more ($P<.01$) as the temperature decreased (figure 2). The correlation coefficient for this regression was -0.50.

The time spent lying was not affected by housing system or feeding level. The overall mean for this behaviour was 25.9 % of the time. Significant sources of variation were temperature and time after sunrise, however these were significant only for the outside animals. The time spent lying increased on mornings when the temperature was low ($P<.01$, figure 3). For each C^{o} drop in temperature, 1.6% more time was spent lying down. The time between sunrise

Table 7. Regressions of rumination, lying, and grooming with temperature (Y=a + b(temperature (C)) for steers (experiment 1)

TRAIT	HOUSING	a	b	S.E. of ESTIMATE	r^2	SIGN.
Rumination (% of time)	outside	0.99	-2.15	37.76	0.25	P<.01
	inside	53.97	-0.71	43.37	0.00	
	all	33.49	-0.25	43.33	0.01	
Lying (% of time)	outside	10.31	-1.58	43.18	0.12	P<.01
	inside	-12.26	0.17	36.87	0.01	
	all	41.94	-0.66	41.94	0.07	
Grooming (#/10 min)	outside	2.354	+0.055	2.016	0.07	P<.05
	inside	3.344	-0.042	2.437	0.00	
	all	2.039	+0.036	2.158	0.08	
Wet Grooming (#/10 min)	outside	1.096	0.023	1.109	0.04	
	inside	1.657	-0.001	1.824	0.00	
	all	1.147	0.026	1.376	0.10	
Dry Grooming (#/10 min)	outside	1.258	0.031	1.566	0.04	
	inside	1.687	-0.041	1.401	0.01	
	all	0.892	0.010	1.518	0.01	

FIGURE 2. RELATIONSHIP OF THE TIME SPENT RUMINATING AND AMBIENT TEMPERATURE FOR OUTDOOR STEERS (EXPERIMENT 1).

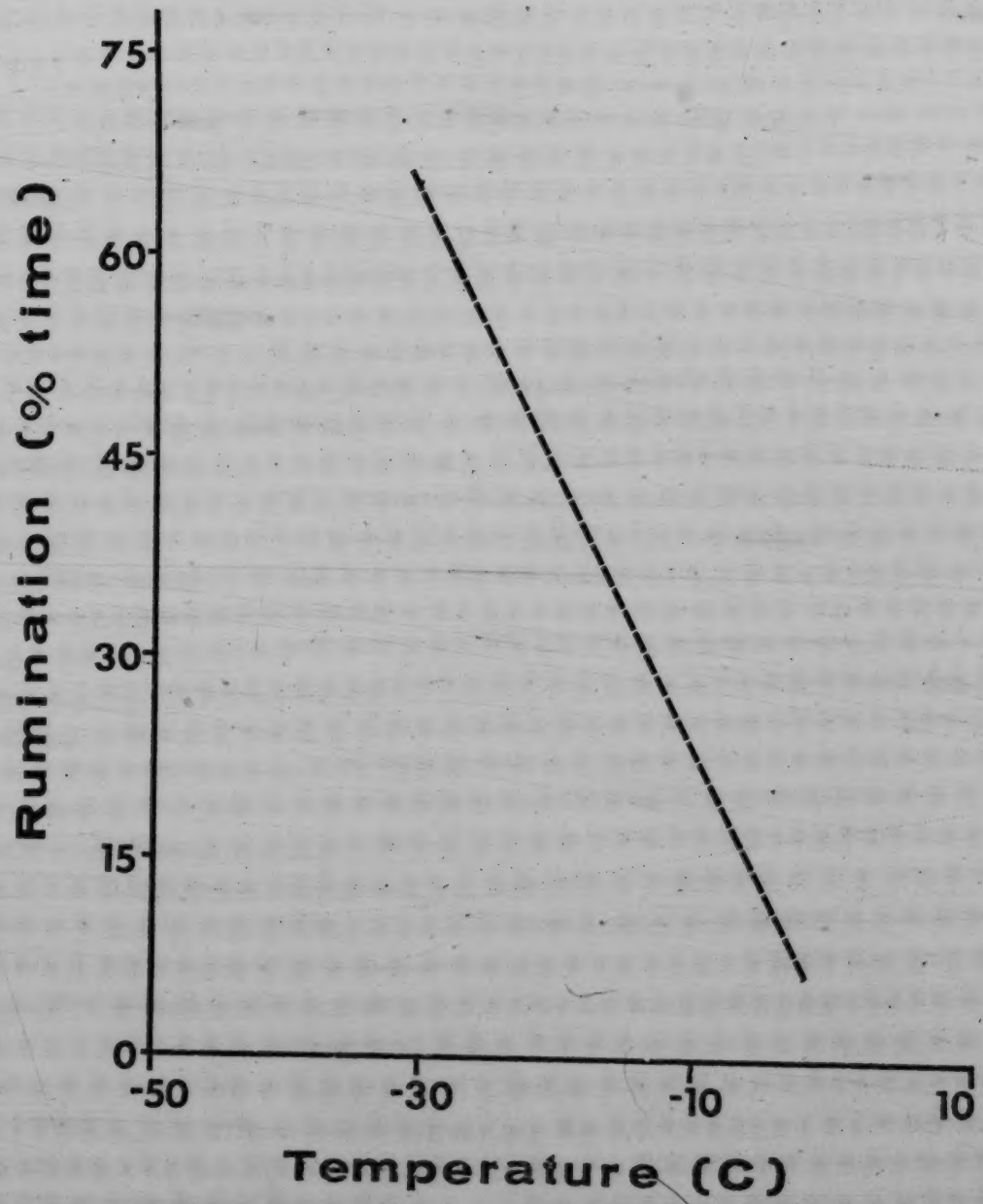
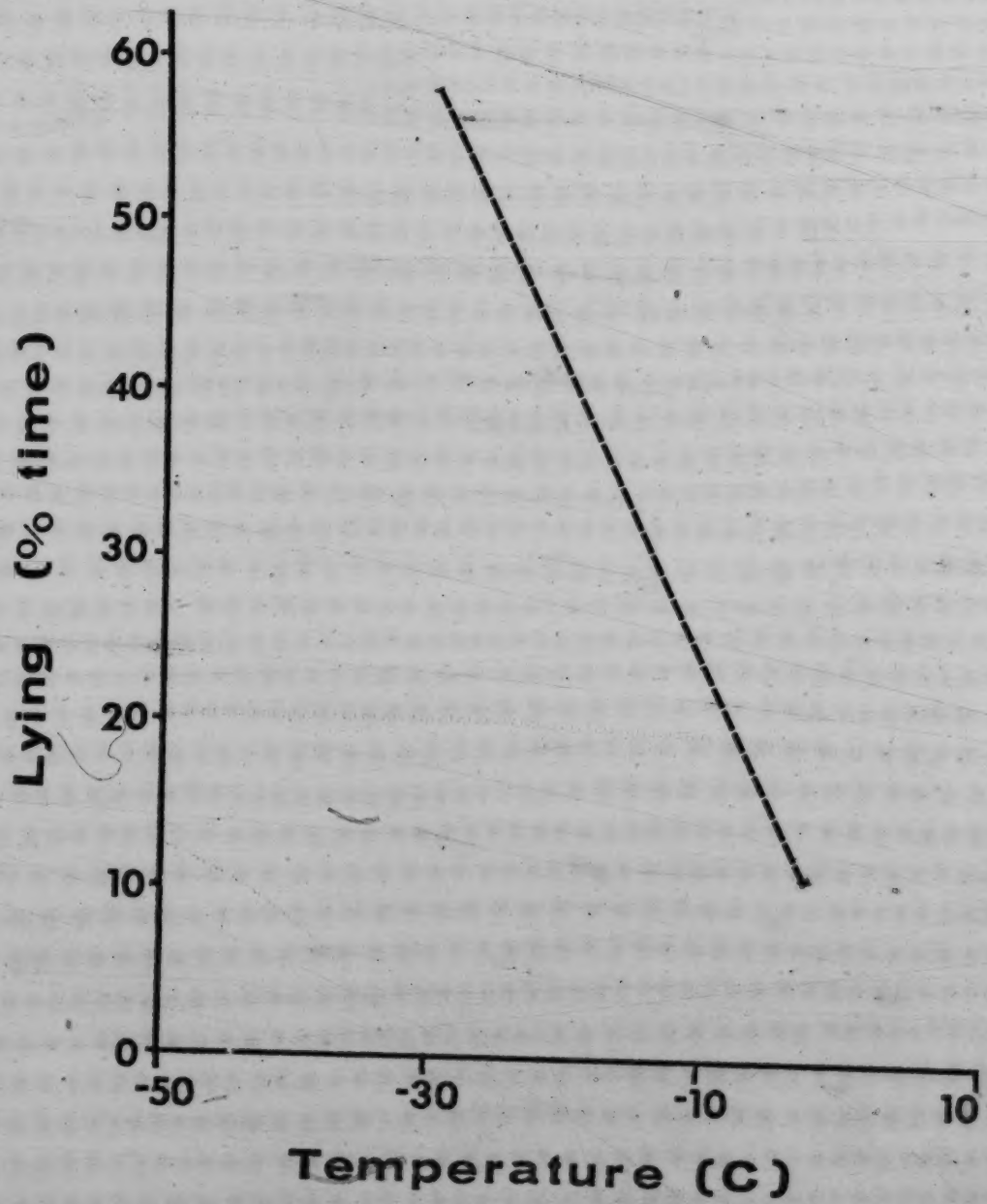


FIGURE 3. RELATIONSHIP OF THE TIME SPENT LYING AND AMBIENT TEMPERATURE FOR OUTDOOR STEERS (EXPERIMENT 1).



and the observation time (figure 4) was inversely related to the time spent lying ($P<.01$).

The relationship between feeding level and total grooming approached significance ($P<.10$) when both inside and outside animals were considered. Neither wet nor dry grooming showed any significant trends over both groups. In the outside steers total grooming increased during warmer weather ($P<.05$). Wet and dry grooming did not show any significant trends although both decreased slightly in the cold (figure 5). The areas of the body licked either by the animal itself or by one of its pen-mates are given in table 8.

Table 8. Location of licking by steers (occurences)

HOUSING	HEAD	SIDE	RUMP	LEGS
outside	3	38	11	13
inside	5	39	15	15

Experiment II

Average water consumption ($\pm$S.D.) per animal per day was 32.5 $\pm$6.1 litres. The relationship of water consumption and body weight was described by the equation ($r=0.84$):

Intake (l/d) = -12.6(l/d) +.055(l/d/kg) X body weight (kg)

Over the entire trial water consumption per 100 kg of body weight increased by 74 ml for every 10 C^{o} increase in temperature ($r=0.55$, $P<.05$). Significant effects ($P<.01$) were also found due to day and a temperature by day interaction.

FIGURE 4. RELATIONSHIP OF THE TIME SPENT LYING AND THE TIME AFTER SUNRISE (EXPERIMENT 1).

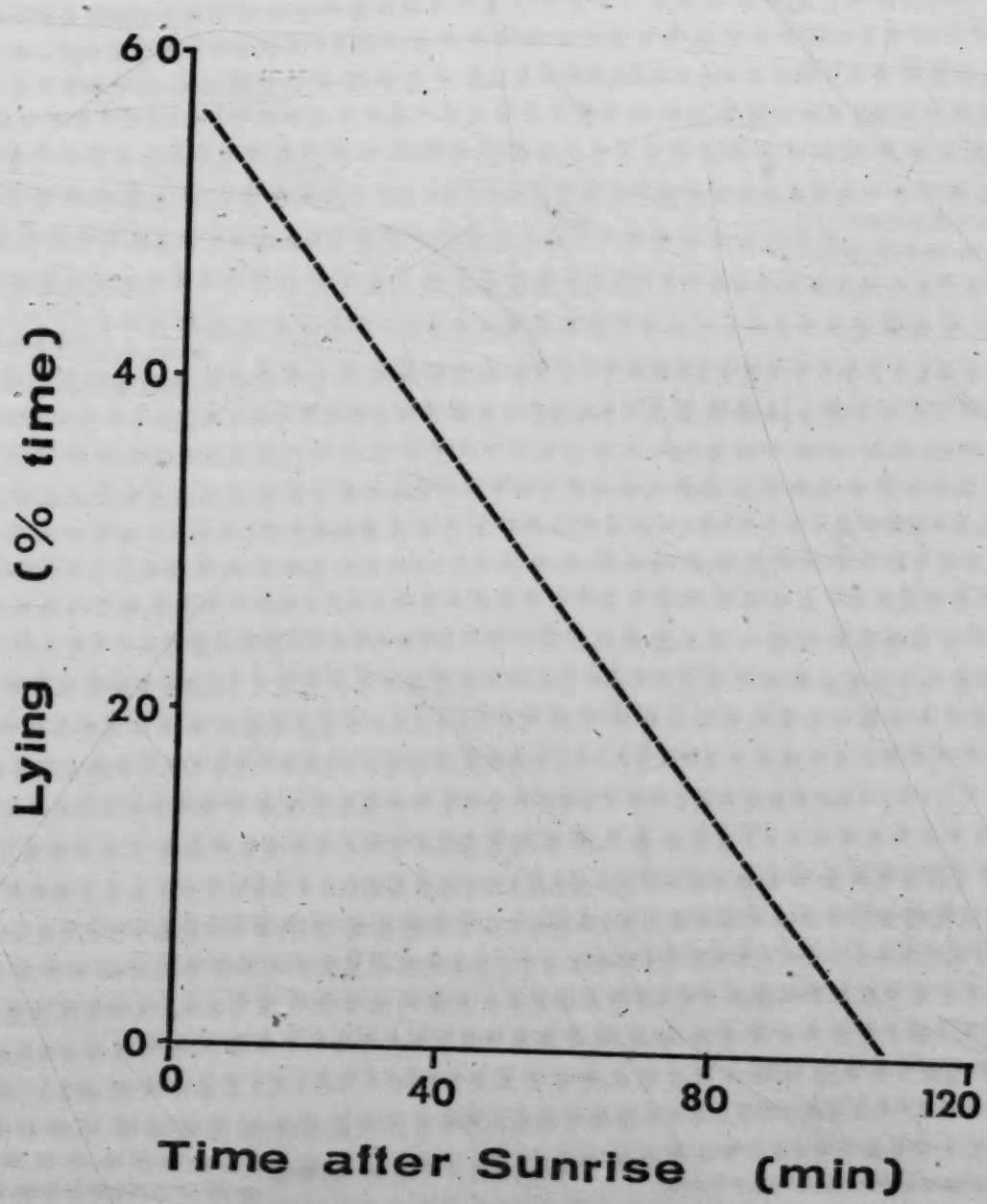
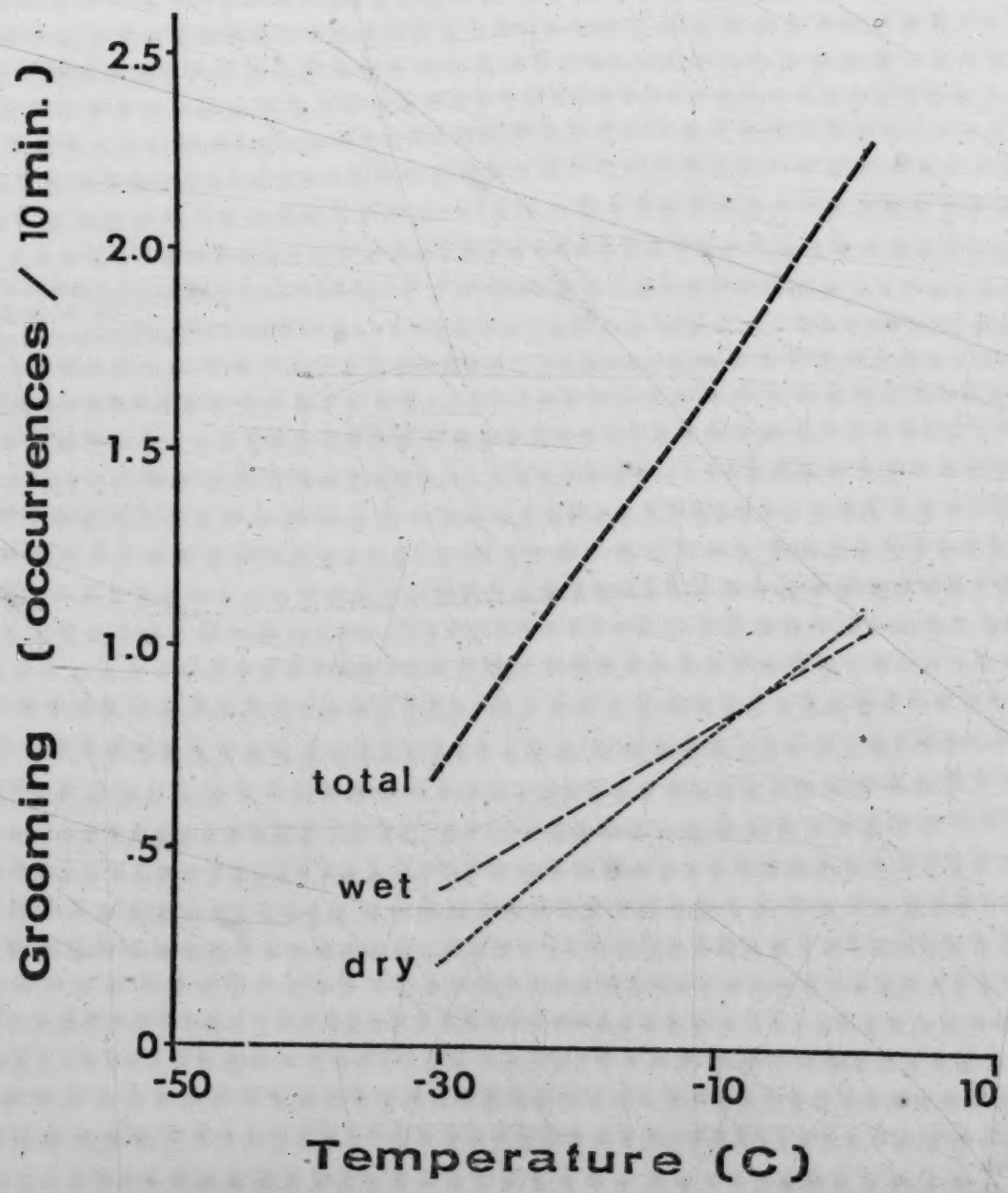


FIGURE 5. RELATIONSHIPS OF THE FREQUENCY OF GROOMING (WET, DRY, AND TOTAL) AND AMBIENT TEMPERATURE FOR OUTDOOR STEERS (EXPERIMENT 1).



During the initial part of the experiment (to February 18) the effects of temperature on water consumption approached significance ($P<.10$, b= 100 ml/100kg/10 C^{o}). Temperature during this period averaged -9.8 C and intake 3.86 litres/ 100 kg B.W. After the change in feed the day effect became significant ($P<.01$) and the effect of temperature (average -2.2) was also significant ($P<.05$, b=0.50 litres/100 kg/ 10 C^{o}). Water intake averages 4.04 litres/100kg B.W. per day during this period.

Experiment III

The mean values of the results of experiment 3 are given in table 9. Rumination in the morning increased during exposure of the steers to the colder temperatures ($P<.05$). The difference between months (10.4% vs. 4.2% of the time spent ruminating for September and December respectively) approached significance ($P<.10$). Rumination during the evening in December was significantly influenced both by steer and temperature ($P<.01$). A decrease in temperature from 20 to -20 C was associated with an increase in time spent ruminating from 12.5% to 31.0%.

The frequency of reticular contractions was not significantly related to the steer or month. The increase in motility during exposure to the colder environments approached significance ($P<.10$). The frequency during rumination averaged 1.1 contractions per minute compared to 1. contractions per minute when the steers were not

Table 9. Effect of temperature on behaviour of steers during fall and winter (experiment 3)

TRAIT	PERIOD	TEMPERATURE -20	TEMPERATURE 0	TEMPERATURE +20	MEAN (M)	GRAND MEAN ±S.E.
Rumination (% time, am)	Sept.	15.6	13.6	0.8	10.0	
	Dec.	8.9	3.6	0.0	4.2	
	mean	12.2[a]	8.6[ab]	0.4[b]		7.1 ±2.58
(% time, pm)	Dec.	31.0[a]	16.7[b]	12.5[b]	20.1	
Reticulum motility (Contractions/min)	Sept.	1.14	1.11	0.92	1.06	
	Dec.	1.01	0.95	0.87	0.94	
	mean	1.08	1.03	0.89		1.00 ±.05
Reticulum motility during rumination (contractions/min)	Sept.	1.27	1.23	0.89	1.19	
	Dec.	1.11	1.21	--	1.14	
	mean	1.20	1.22	0.89		1.18 ±.05
Reticulum motility when not ruminating (contractions/min)	Sept.	1.13	1.09	0.92	1.05	
	Dec.	1.01	0.94	0.87	0.96	
	mean	1.07	1.02	0.89		1.00 ±.03
Lying (% time)	Sept.	0	3.8	20.0	7.9	
	Dec.	0	0	9.4	3.1	
	mean	0[a]	1.9[a]	14.7[b]		5.5 ±1.98
Respiration frequency (breaths/min)	Sept.	15.0	17.4	36.4	22.9[a]	
	Dec.	12.4	18.1	63.3	31.3[b]	
	mean	13.6[b]	17.7[b]	49.9[a]		27.1 ±2.73
Rectal temperature (C)	Sept.	38.00	37.73	38.75	38.17	
	Dec.	38.00	38.68	38.63	38.47	
	mean	38.05[a]	38.21[b]	38.72[b]		38.32 ±.11

a,b,c means with different letters differ significantly ($P<.05$)
(M) month

ruminating. This difference was significant ($P<.01$).

The time spent lying increased from 0 to 14.7 % of the time as temperature was increased from -20 to 20 C ($P<.01$). No significant differences were found between steers or months for this trait.

The animals did not shiver at 20 C. Only one steer (#335) was observed shivering at 0 C, and only during the September trial. All animals shivered at -20 C in both September and December trials. The most severe instance of shivering, involving a definite arch in the back was observed in steer #609 in September.

Respiration frequencies were significantly lower ($P<.01$) during exposure to the colder temperatures, and in September as compared to December ($P<.05$). The interaction of month and temperature was significant ($P<.05$) indicating that although respiration frequency at -20 C decreased there was a substantial increase in the values obtained at 20 C in December as compared to September.

The rectal temperatures of the steers were significantly lower ($P<.05$) during exposure to -20 C than during exposure to 20 C. No significant difference was present between periods.

DISCUSSION

The production results from experiment 1 indicate that the outdoor environment reduced the efficiency of the animals, as measured by average daily gain, by an average of 43%. Self et al. (1963) and Bennett and O'Mary (1975) found that production was reduced 16 and 25% respectively when their animals were kept outdoors and compared to indoor controls. The greater effect observed in this experiment is probably due to the indoor environment being heated and the more severe winter conditions encountered (minimum temperature of -40 C). The cattle of Bennett and O'Mary's experiment experienced a minimum of only -20 C.

Another reason for the large effect on gain is due to the feeding levels used. The animals on the maintenance level of ration would be expected to have little if any metabolizable energy available for growth. Even a slight increase in maintenance costs due to the cold temperatures would greatly reduce the proportion of energy available for tissue production. Thus, feed efficiency and overall gain was very poor for the outdoor maintenance fed animals.

The difference in gain between the indoor and outdoor animals may also have been underestimated by the method of analysis used. The inside animals lost weight temporarily during the periods of total collection

and regained it during the following week. However, the lower recorded weights of the collection period would tend to reduce the slope of the least squares regression line used to determine gain. The result would be an estimate of growth that was less than the actual gain.

The packed cell volume of the blood from the outdoor steers was greater than that from the indoor animals. Both red blood cell count and haemoglobin content also tended to be higher in the outdoor animals exposed to the winter conditions as compared to those indoors. These results are what would be expected in animals exposed to cold conditions as blood volume would decrease (Thauer, 1965) and the total red blood cells increase (Everett and Matson, 1961). Haemoglobin, contained in the red blood cells, is the principle carrier of oxygen and carbon dioxide in the blood. During exposure to cold environments greater volumes of these gases must be exchanged and the increased concentration of haemoglobin in the blood is an adaptive mechanism to meet this need more easily. Although the measurements did not show any consistent trend between feeding levels they do indicate that the outdoor animals responded in a typical manner to the winter environment.

The decrease in packed cell volume in March as opposed to February, particularly noticable in the out-

door animals, indicates that the effects of winter on the steers was decreasing. Although some of the monthly differences may have been due to the different sampling sites the interact ion indicates the outdoor animals responded to a greater extent than those inside to spring conditions.

The white cell count was not significantly affected by housing systems. Although eosinophil counts may be reduced in acute cold exposure (Mears and Groves, 1969) the effect on total white cell count would be insignificant as eosinophils represent only 1 to 3% of the total count (Guyton, 1971).

The thyroid hormone values are measurements of circulating levels only and although indicative of changes in hormone status do not provide information as to the specific changes in thyroid metabolism. Although many studies have been made on the effects of the thyroid hormones in small animals their actions in larger animals are not as well known. Balch (1952) and Balch et al. (1952) did observe a slight increase in the reticular contraction rate and a decrease in the retention time of ingesta when dairy cattle were fed thyroxine. Westra and Christopherson (1976) found that increases in serum T_3 concentrations in sheep exposed to cold temperatures were related to a decrease in the retention time of Ce^{144} in the digestive tract and an increase in reticular motility. It has been shown by Yousef et al., (1965) that the I^{131} turnover

rate is greater in cold exposed cattle indicating an increased rate of production and utilization of thyroid hormones. It has been suggested that the role of these hormones during cold exposure is to potentiate the effect of catecholamines (Swanson, 1957) but only a basal level is needed to produce this effect (Sellers and You, 1950). Webster (1974) states that the role of thyroid hormones in response to cold environments is not clear, particularly during long term exposure.

The increases in T_4, T_3, and T_3/T_4 values in the outdoor animals are similar to the results obtained for sheep by Westra and Christopherson (1976). The increase in the thyopac index values indicate that there is an increase in the level of circulating T_4 in an unbound state during cold exposure. The decreases in thyroid hormone values in March compared to February may have been due to the occurence of milder weather in March or may have been an indication that the animals were returning to normal thyroid status as has been observed in other species after long periods of cold exposure (Heroux, 1960). In this case the first explanation is more probable as the animals had already been acclimatized for several months before the first blood analysis was made.

The cattle on the lower levels of nutrition had greater free-standing hair coat depths. The hair coat, including the dead air space associated with it, forms

an insulative barrier between the skin and the air. The increased thickness would increase the insulation value of the coat and conserve heat. This would be particularly important for the animals on the lower feed intakes. The increase in coat depth on the outside animals was not statistically significant but may indcate a trend that would be advantageous for the outside animals. Webster et al. (1970) did find greater hair coat depths in outdoor compared to indoor cattle.

The compressed hair depths were not significantly different for any treatment. This may indicate that the greater free-standing coat depth of some animals was due to increased pilo-erection rather than to increased hair coat. The low level of precision involved in measuring the compressed coat depth may have precluded finding any significant difference since only slight differences in depth could be expected.

The rectal temperatures of the animals did not vary a great deal over the wide range of environmental temperatures. The work of Bligh and Hawthoorn (1965) and Bligh et al. (1965) indicates that homeotherms, particularly sheep, are very efficient in maintaining rectal temperature. The very small decrease in rectal temperature associated with decreased ambient temperature in experiment 1 also supports this. The slight, though not significant, increase in rectal temperatures in December as opposed to September in experiment 3 might

be attributed to an increased resistence to body cooling as indicated by the work of Sykes and Slee (1969a) and Slee (1970, 1972, and 1974) on habituation and acclimation of sheep to cold temperatures.

In experiment 1 the apparent ability to tolerate increasingly colder temperatures without shivering as the winter progressed probably indicates an effect of acclimatization. The failure of any steers to show visible signs of shivering at 0 C in December in experiment 3, along with the decreased intensity of shivering in December compared to September, also suggests the occurence of acclimatization. Young (1975) found that shivering was eliminated after two weeks of exposure to -10 C in cows and that the intensity of shivering progressively decreased at -25 C during extended exposures. Sykes and Slee (1968) found that Scottish Blackface sheep, acclimatized to cold temperatures, showed less shivering during acute cold exposure than did non-acclimatized controls. However, Southdown and Welsh Mountain sheep shivered equally whether acclimatized or not (Sykes and Slee, 1969b).

Although shivering generates additional heat for maintenance of body temperature by muscular activity no net work is done and the process involves energy that could otherwise be available for production. The function of shivering is to provide extra heat during periods of excessive heat loss. The reduction of shivering during

winter, even though ambient temperatures remained low, indicates either that heat loss had been reduced, that another source of heat was being utilized, or that both had occurred. Heat loss may have been reduced by better insulation due to an increased hair coat or by more efficient vaso-constriction near the body surface. The increased resting metabolic rate that accompanies acclimatization to cold environments (Young, 1973) would help to eliminate the need to shiver until the temperatures became very severe. The two experiments in which shivering was recorded involved several months of outdoor exposure and acclimatization was to be expected.

The frequency of shivering was not significantly different between feed levels. Sykes and Slee (1969b) failed to mention if there was any difference in shivering between sheep on different levels of feed intake in their experiment. However, the trend toward increased frequency of shivering in the low feed level animals and the apparent severity of shivering indicates that these animals were probably more susceptible to the cold conditions. Observations on a greater number of animals during a severe winter are needed to substantiate this suggestion.

Respiration frequency is indicative of the heat status of the animal. As temperatures increase to a point when non-evaporative means of heat loss are not adequate to dissipate the heat of metabolism the animal

must resort to evaporative means such as sweating and moisture loss from respiratory tract. Respiratory frequency increases at warmer temperatures in order to cycle more air over the moist surfaces of the upper respiratory tract. Respiratory frequency is lowest when the animal is exposed to temperatures below its lower critical temperature. Webster (1973) states that frequencies of 20 breaths/minute are observed below the lower critical temperature and may increase to 80 breaths/minutes before the upper critical temperature is reached. Above this point panting is common in order to rid the body of the excess heat.

In experiment 1 the respiratory frequencies decreased in the colder temperatures similar to the results of MacDonald and Bell (1958b). The animals on the higher feeding levels increased their respiratory frequency to a greater extent than the steers on the lower feed levels as the temperature increased. This indicates that the animals on the low intakes had higher lower critical temperatures. These results agree with the patterns of evaporative heat loss in sheep on different feed levels (Blaxter, 1967).

In experiment 3 respiratory frequencies were directly related to temperature. In addition, the frequencies at -20 C were lower in December than in September. This would indicate that the animals had adapted to cold exposure between the two periods and may have been able to further decrease their evaporative heat loss from the respiratory

tract in the cold conditions. There is evidence that the evaporative heat loss by sheep and cattle reaches a minimal rate that remains approximately constant at temperatures below the lower critical temperature (Blaxter, 1967). It would be interesting to establish whether the minimal rate of evaporative heat loss can, in fact, be further reduced by acclimatization as suggested by the lower respiratory frequencies observed at -20 C in December compared to September. In December the animals also exhibited a panting type of respiration at 20 C not observed in September. Apparently more heat had to be dissipated by evaporative means at 20 C in December than in September. Young (1975) observed a similar decrease in respiration frequency at low temperatures and an increase in respiration frequency at 20 C in cows after adaptation to cold. Animals that are winter acclimatized appear to be more susceptible to heat stress at moderate temperatures than non-acclimatized animals.

The results discussed so far indicate that the animals kept outside in experiment 1 were cold stressed and underwent winter acclimatization. Some effects of their adaptation to cold decreased as spring approached. The animals fed lower levels of feed were more susceptible to cold temperatures than those on high levels of intake. The animals in experiment 3 underwent similar acclimatization to early winter conditions between September and December.

Experiments 1 and 3 produced conflicting results in

terms of the relationship between temperature and time spent lying down. In experiment 1 the outside animals spent more time lying down during colder temperatures. The opposite relationship was seen in experiment 3. Malechek and Smith (1976) found that the time spent standing by range cows was inversely related to temperature, similar to the results of experiment 3. Blaxter and Wainman (1961) found that their steers kept in environmental chambers stood more at -5 C than at warmer temperatures up to 25 C. The results of the outside steers in experiment 1 differ from the other experiments mentioned.

There are several possible reasons for these conflicting results. Experiment 1 involved observations over a relatively short period and at a standard time during the day whereas the other experiments involved periods of several hours or several observations throughout the day. A different response to temperature at different times during the day is a possible explanation for the conflicting results. In this case cold temperatures in the early daylight hours may have delayed arousal and resulted in greater lying values during cold periods in experiment 1.

Another explanation may be the different bedding conditions of the experiments. The trials in the chambers were conducted without provision of bedding so that an animal lying down would find little insulation

value in the flooring with accumulated feces and urine. The animals in the range study, although probably having access to dry areas, would not find a great depth of bedding material. The steers kept outside in experiment 1 were bedded regularly and were on an accumulated manure pack. Greater insulation in the bedding material would make lying down a more acceptable alternative during cold exposure.

The influence of the time of sunrise on lying behaviour is not unexpected. Hafez (1969) indicates that cattle spend much of the night lying down. Sunrise is a stimulus to begin daytime activities and observations near the time of sunrise would find more cattle lying than later in the day. However, the reason for the diurnal pattern of activities is not clear. Besides illumination sunlight also provides radiant energy which may make some activities more acceptable at different times during the day. Although studies using radiant energy under cold conditions have been made with pigs (Ingram, 1975: Ingram and Legge, 1970) and sheep (Baldwin, 1975) only theoretical results from a model ox are available for cattle (Webster, 1971). Studies on the radiant environment and its effect on the behaviour of cattle in the cold are needed.

Grooming does not have a well defined function in cattle. Schake and Riggs (1966) found that adult cattle averaged 152 licking periods and 28 scratching periods each day. Social grooming occurs and is usually between animals

close to each other in the social order (Schloeth, 1961). Self grooming and cow-calf grooming have been related to parasite control (Bennett, 1969; Rich, 1973). Hafez (1969) suggest that salt or some other desirable compound present on the hair may be a stimulus for both self and social grooming.

In this experiment the outside animals decreased their grooming during cold days. Both wet and dry grooming showed a decrease in the cold although neither were significant in themselves. Colder temperatures would reduce sweating and therefore reduce salt content of the pelage. This could be a possible explanation for the reduced frequency of wet grooming. Both wet and dry grooming may be reduced if cold conditions reduce the grooming stimuli or the animals sensitivity to the stimulus. Sensation of the cold temperatures may divert the animals attention from grooming.

Grooming behaviour has adverse effects on heat loss which may reduce its frequency during cold exposure. Licking or scratching involve relatively sudden changes in body flexure and the resulting cooling effect may act as a negative reinforcement for grooming. Licking also wets and compresses the hair coat and thus reduces the insulation value.

The effect of temperature on water consumption is influenced by several factors. Studies have shown that water requirements are greater in the summer than in the winter (Longhurst et al. 1970; Hoffman and Self, 1972).

This would be expected due to the increased need for evaporative heat loss at the higher temperatures. When first exposed to cold, animals were reported to decrease water consumption (Bailey, 1964; Bailey, Hironaka and Slen, 1962; Young, 1975). In a review of body fluid responses to cold Bass and Henschel (1956) indicated that, during a brief exposure to cold temperatures, body fluid volumes decrease. If the cold conditions persist, the body fluids return to the levels found in animals maintained in thermoneutral environments. This does not necessarily mean that water consumption must return to normal, as water turnover has been shown to decrease in the winter in reindeer (Cameron and Luick, 1972).

Under winter conditions the water requirement for evaporative heat loss is very low and not subject to great variation. In long term studies involving winter conditions water consumption trends are conflicting. MacDonald and Bell (1958a) found that water consumption and total water intake by lactating dairy cattle increased during cold periods. Hoffman and Self (1972) found that water consumption decreased on cold days when steers were fed ad libitum. Williams (1959) obtained results similar to the latter authors in a study with feedlot steers.

In experiment 2 the water consumption of the bulls decreased by a small percentage on cold days. This general trend is similar to that observed by Hoffman and Self (1972) and Williams (1959) who also studied growing cattle.

MacDonald and Bell (1958a) attribute the increase to a greater feed intake on cold days as the water/feed ratio remained constant. The feedlot studies of the other authors did not provide feed intake data and this was not available on a daily basis for the bulls in experiment 2. It is possible that the feedlot cattle did not increase their feed intake sufficiently to increase water consumption during cold exposure as was the case in the dairy cattle. The fact that the dairy cattle were lactating may have increased their need to maintain their water/feed intake ratio even in cold temperatures.

Because of the high correlation between water and feed consumption, studies involving water/feed intake ratios during cold exposure in feedlot cattle would add to our knowledge of cold stress. Studies have been made using pigs (Mount et al., 1971) and sheep (Westra and Christopherson, 1976) which indicate that the water/feed intake ratio decreases during cold exposure. Studies of water consumption of cattle on fixed feed intakes would also indicate the effects of cold environments on water intake.

Estimates of the shavings intake from individual samples varied considerably between analytical methods although the average intakes determined by reference to AIA and Cr_2O_3 over the entire experiment were nearly identical. While estimates of individual shavings intake by either method may involve errors of $\pm$10%, there is no

alternative method that is likely to be more accurate and analysis of a large number of samples by either the AIA or Cr_2O_3 technique compensates to some extent for the large variability.

The average shavings consumption of approximately 1 kg/steer/day represented 10 to 20 % of the total dry matter intake of the steers and would greatly influence any digestibility estimates which did not take shavings consumption into account. Digestibility trials with feedlot cattle are definitely complicated by bedding material.

The shavings intake was increased slightly in colder weather. This may be due to the fact that the animals were not fed their ration to appetite. Increasing shavings intake was the only means of increasing dry matter intake during cold weather. The increase in digestible energy would be negligible, however, because of the poor digestibility of shavings.

Because the animals were restricted to less than 3 hr for actual feeding each day, shavings consumption may have been a means of maintaining a normal eating pattern throughout the day. It is of interest that the maintenance fed cattle did not consume significantly more shavings than those on the highest nutritional level. Consumption of shavings may be an allelomimetic type of behaviour similar to grazing, with all animals generally involved as a group (Hafez, 1969). Sheep fed on two levels of

concentrate and then allowed to graze together spent equal amounts of time grazing, but when grazed in groups according to concentrate intake level grazing times were different (Tribe, 1950). In experiment 1 all feeding levels were grouped into each pen and would function as one group.

When digestibility was regressed against temperature, after standardization for housing, method, shavings intake and feed level, digestibility of the feed decreased 0.29 % for each C^{o} drop in temperature. This is greater than the decreases reported by Blaxter and Wainman (1961) and Christopherson (1976). In the case of Christopherson's report it should be noted that the decrease was calculated be comparing inside cattle to outside and using the temperature difference between the two housing systems as the temperature change. This method of calculation may not give a correct estimate of the effect of temperature per se since it is not known to what extent the housing differences may have been influenced by other variables (such as radiation, humidity, dust etc.). The estimate in the present experiment involves a regression against actual temperature. The temperature range in experment 1 was only 21 C^{o} for the outside cattle and 7 C^{o} for the inside.

The digestibility estimates showed a great deal of variation. The majority of the variation in digestibility estimates between analytical methods was associated with the variation in shavings intakes estimated by either AIA

or Cr_2O_3. Any difference in shavings consumption was magnified in the calculation of digestibility. Before a digestibility estimate could be made 4 and 6 laboratory determinations were necessary for the Cr_2O_3 and AIA methods respectively. Some of these determinations were involved in the calculations more than once. Because of the variability possible in the laboratory analysis the error associated with an estimate of digestibility is expected to be high. In the analysis of variance for both shavings intake and digestibility only one third of the variation was explained by the factors tested. Although the mean digestibility value of 65.8% is approximately what would be expected for the type of ration fed, the range of 47.3 to 79.6 % is perhaps larger than one would expect.

In the calculations made for shavings intake it was assumed that any material that the animals consumed other than their ration was shavings. This may not have been the case. Although cattle tend to avoid eating material contaminated with excreta it may be consumed when the entire area is contaminated (Tribe, 1955) as was the case in this experiment. Contaminated shavings would have a greater level of AIA and Cr_2O_3 and less lignin in them than non-contaminated shavings, and the resulting estimate of shavings intake would be lower than the actual value. The result of the digestibility estimate of shavings intake would be lower than the true value as well. Thus, the degree of contamination of the consumed shavings would

affect the estimates obtained.

Further discrepancies result from the unequal use of two markers as in this experiment. AIA was added to the accumulated shavings in feces throughout the experiment while Cr_2O_3 was added intermittently during trial periods. The level of AIA in the bedding material would be more consistent than the Cr_2O_3 as the Cr_2O_3 levels would flucuate with trial periods. The difference between the marker levels in the shavings used for calculations and the levels in the bedding consumed, would be greater for the AIA concentrations than for the Cr_2O_3. For this reason Cr_2O_3 produced a higher and possibly more accurate estimate of shavings intake and digestibility than did AIA. Because the Cr_2O_3 trials were generally associated with periods when the outside animals had access to shavings and the inside animals did not it is not surprising to find that the interactions of method with housing and temperature were significant. However the extent of the problem of re-ingested material can not be determined in this experiment.

The failure of the total collection method to produce any significant results may also be attributed to too great a level of variation. The pens used as collection stalls allowed errors such as cross-pen contamination and washing away of feces by urine and water to occur. Although attempts were made to minimize the problems they were not totally resolved. In addition, the shavings intake

estimates during the periods of total collection indicate that some shavings, consumed prior to confinement, were still being excreted several days later. This would add bulk to the feces and reduce digestibility estimates.

The increase in rumination on cold mornings in experiment 1 was significant. Part of this increase may have been due to increased shavings consumption and the resulting stimulation of rumination by the coarse material (Welch and Smith, 1971). However, the steers in experiment 3 were fed the same diet throughout and also ruminated more during the colder trials.

Rumination, although occurring at any time of the day, is greatly increased at night (Gordon, 1958; Wilson and Flynn, 1974, 1975). Because all of the observations in experiment 1 were in the morning the increase in rumination may have been only a shift in the daily pattern of activity associated with cold conditions. In experiment 3 however, the cattle also increased rumination in the evening precluding a simple shift in diurnal activity.

In experiment 3 the reticulum motility of the steers was greater during rumination. Reticular motility is associated with the rate of passage of ingesta (Balch, 1961). Westra and Christopherson (1976) reported greater reticular motility of sheep during cold exposure but rumination was not recorded. Other workers have not found an increase in motility during rumination (Osuji, Gordon and Webster, 1975) and some report a decrease (Balch, 1952).

Contractions of the reticulum occur between the chewing of each bolus involved in rumination (Balch, 1961). Whether rumination increases motility depends on the time spent chewing each bolus, which has been show to be influenced by diet (Gordon, 1965). These dietary effects may explain the conflicting results of the effect of rumination on reticular motility. The changes in the rate of passage in sheep exposed to cold reported by Westra and Christopherson (1976) may have been due to an increase in reticular motility, but this increase was not necessarily due to rumination.

Rumination itself has been associated with an increased rate of flow of ingesta to the abomasum (Gordon, 1955). This increased flow has been explained by LaPlace (1970) as being due to increased activity in the omasum rather than in the reticulum. It should be noted that the rate of flow is determined not only by the propelling forces of the various contractions but also by the resistance to the flow offered by the various orifices encountered. Thus, an increase in the rate of reticular contractions is not essential for rumination to be associated with more rapid passage of ingesta.

An increase in rumination and the associated rate of flow has been shown to increase the rate of passage of ingesta and to decrease digestibility in sheep (Pearce and Moir, 1964). It is postulated from the present study that at least part of the decrease in the digestibility

of feeds associated with cold exposure of ruminants is due to the effects of increased rumination.

Removal of the omasum in a sheep eliminates rumination (LaPlace, 1970), indicating that rumination is dependent on, and may be regulated by this part of the stomach. The omasum is innervated by the vagus nerve which has been shown to increase its activity during cold exposure (LeBlanc and Cote, 1967) and during spinal cooling (Iriki and Kozawa, 1976); probably due to an integration of temperature sensations in the hypothalamus. A possible mechanism for the increased rumination observed during cold exposure is by stimulation of the rumination centre by afferent neural impulses from the omasum which is stimulated by increased vagal activity. An alternate possiblity is that the rumination centre is stimulated directly by some region of the central nervous system that integrates temperature sensing imputs. In this case the omasum would serve a potentiating role. Further research on the neural control of rumination is needed to establish the mechanism involved during cold exposure.

Conclusions

Under the conditions of these studies it is concluded that:

1. Production efficiency was reduced in cattle wintered outside as opposed to a heated barn and in those on low as opposed to high feed intakes.
2. Circulating thyroid hormone levels were increased in cattle exposed to winter conditions. The ratio of T_3/T_4 and the levels of unbound T_4 were also increased.
3. The hair coat depth was greater for animals on low as opposed to high feed intake levels.
4. Rectal temperatures of cattle decreased only slightly when the animals were exposed to cold winter conditions.
5. The maximum temperature at which shivering occurred was reduced as the winter progressed.
6. Respiration frequencies were reduced in cold temperatures and the increase when exposed to warmer temperatures was greater in cattle on high feed levels than in those on low levels. Animals exposed to 20 C increased their respiration frequency to higher levels after acclimatization than before.
7. Cattle having adequate bedding spent more time lying down on cold days than on warm when observations were made in the morning. Cattle in environmental chambers having no bedding spent less time lying down during cold exposure as opposed to warm.
8. Cattle exposed to winter conditions groomed less on

cold than on warm days.

9. Bulls on ad libitum feeding reduced their water consumption/kg body weight on colder days.
10. Cattle bedded on shavings consumed significant amounts of that material, particularly during cold periods. Animals within the same pen but receiving different amounts of feed consumed approximately equal amounts of shavings.
11. Digestibility of feed was greater during warm periods than during cold.
12. Time spent ruminating increased during cold exposure. Reticular contractions in cattle fed long stemmed hay were more frequent during rumination than when the animal was not ruminating.

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APPENDIX

APPENDIX 1

PROCEDURE FOR THE DETERMINATION OF LIGNIN IN FECES

Ref. Association of Official Agricultural Chemists. 1975. Methods of Analysis-AOAC. Washington.

Van Soest, P.J. 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. J. Assoc. Off. Agric. Chem. 46:829.

Reagents

1. Acid-detergent solution.
   a) Cetyl trimethylammonium bromide (CTAB)
   b) 1.0 N H_2SO_4 (49.04 g/l)
   Dissolve 20 g CTAB in 1 l of acid solution.

2. Decalin- reagent grade decahydronaphthalene.

3. Acetone- distilled.

4. Saturated potassium permanganate ($KMnO_4$).
   Dissolve 50 g $KMnO_4$ in 1 l distilled water. Keep out of direct sunlight.

5. Lignin buffer solution.
   Dissolve 6.0 g ferric nitrate nonahydrate ($Fe(NO_3)_3 \cdot 9H_2O$) and 0.15 g silver nitrate ($AgNO_3$) in 100 ml of distilled water.
   Combine with 500 ml of glacial acetic acid and 5.0 g potassium acetate.
   Add 400 ml tertiary butyl alcohol and mix. Use grades of acid and solvent passing the dichromate test (ACS).

6. Combined permanganate solution.
   Mix saturated $KMnO_4$ and lignin buffer solution in the ratio of 2:1 (v/v) before use. Solution is usable if it is purple and contains no precipitate.

7. Demineralizing solution.
   Dissolve 50 g oxalic acid dihydrate in 700 ml 95% EtOH. Add 50 ml concentrated (12 N) HCl and 250 ml of distilled water. Mix.

8. Ethanol 80%.
   Mix 200 ml H_2O and 800 ml 95% EtOH.

Procedure

1. Weigh 1.0 g finely ground air-dry sample.

2. Add 100 ml cold (room temperature) acid-detergent solution and 2 ml decalin.
Heat to boiling in 5 to 10 minutes. Reduce heat to avoid foaming as boiling begins.
Reflux 60 minutes from onset of boiling. Adjust boiling to a slow, even level.

3. Filter through filter cloth (lab coat) with hot (90 to 100 C) water twice. Repeat wash (2X) with acetone breaking up all lumps so that the solvent comes into contact with all particles of fiber.

4. Transfer all residue into a crucible with hot water.

5. Dry at 100 C 8 hr or overnight. Cool in a desiccator and weigh. Residue is acid detergent fiber.

6. Add about 25 ml of combined saturated $KMnO_4$ and lignin buffer solution to the crucibles.

7. Place a short glass rod in each crucible to stir contents, to break lumps, and to draw solution up the sides of the crucibles to wet all particles.

8. Allow crucibles to stand at 20 to 25 C for 90 $\pm$ 10 minutes, adding more solution if necessary.
Purple colour must be present at all times.

9. Decant liquid into filtering cloth. Fill crucibles no more than half full with demineralizing solution. After 5 minutes transfer all crucible contents on to the filtering cloth and repeat washing until fiber is white.

10. Thoroughly wash fiber (and crucibles) with 80% ethanol. Repeat two times. Wash twice in similar manner with acetone.

11. Transfer all residue, with hot water, back into the crucible.

12. Dry at 100 C overnight, cool and weight.

Calculate lignin content as loss in weight from acid-detergent fiber.

$$\% \text{ lignin} = 100 \times \frac{(\text{wt cruc.} + \text{ADF}) - (\text{wt cruc.} - \text{lignin})}{\text{wt sample}}$$

APPENDIX 2

PROCEDURE FOR THE DETERMINATION OF Cr_2O_3 IN FECES

Ref: Czarnocki, I. R. Sibbald and E. V. Evans, 1961. The determination of chromic oxide in samples of feed and excreta by acid digestion and spectrophotometry. Can. J. Anim. Sci.

Reagents and Equipment

1. Concentrated nitric acid.
2. Concentrated sulfuric acid.
3. Digestion Mixture: dissolve 10g sodium molybdate in 150 ml of water. Place the container in an ice bath and slowly add 150 ml of concentrated sulfuric acid. After cooling add 200 ml of 70% perchloric acid with stirring.
4. 100 ml Kjeldahl flasks calibrated to 110 ml.
5. Micro-Kjeldahl digestion unit.
6. Beckman DBG spectrophotometer.

Procedure

1. Weigh sample, containing approximately 10 mg Cr_2O_3, wrap in filter paper and transfer to 100 ml Kjeldahl flask.
2. Add 10 ml concentrated nitric acid and allow to stand overnight.
3. Heat to dryness on micro-Kjeldahl digestion unit without charring.
4. Add 15 ml of digestion mixture and digest over low heat until white fumes appear. Digest over high heat until green color changes to yellow, orange or red (depending on chromium concentration). Heat for an additional 5 minutes following color change.
5. Remove flask and allow to stand at room temperature to cool for handling.

6. Add 60 ml of distilled water, then 20 ml of concentrated sulfuric acid and bring flask contents to volume (110 ml) with distilled water.

7. Cool to room temperature, and bring up to volume.

8. Seal flasks and allow to stand overnight to precipitate inorganic material.

9. Read optical density at 450 mμ.

APPENDIX 3

FORMULAE FOR DETERMINING DIGESTIBILITY OF FEED AND SHAVINGS INTAKE USING 2 MARKERS

Symbols:

M^1 concentration of marker 1

D digestility expressed as a fraction (eg. 0.54)

I intake

D.M. dry matter

i,o,s subscripts denoting feed, feces, and shavings respectively

Example: $M_s^2(I_s)$ is the concentration of marker 2 in shavings multiplied by the intake of shavings

Digestibility formula:

$$M_o = \frac{\text{total M input}}{\text{total D.M. output}}$$

$$M_o = \frac{(M_i I_i) + (M_s I_s)}{(I_i - I_i D_i) + (I_s - I_s D_s)}$$

$$I_i - I_i D_i + I_s - I_s D_s = \frac{M_i I_i + M_s I_s}{M_o}$$

$$-I_i D_i = \frac{M_i I_i + M_s I_s}{M_o} - I_s + I_s D_s - I_i$$

$$D_i = \frac{\frac{M_i I_i + M_s I_s}{M_o} - I_s + I_s D_s - I_i}{-I_i}$$

Shavings intake formula:

Assumption: D_i's determined by 2 markers are equal.

Therefore:

$$\frac{\frac{M_i^1 I_i + M_s^1 I_s}{M_o^1} - I_s + I_s D_s - I_i}{-I_i} = \frac{\frac{M_i^2 I_i + M_s^2 I_s}{M_o^2} - I_s + I_s D_s - I_i}{-I_i}$$

$$\frac{M_i^1 I_i + M_s^1 I_s}{M_o^1} = \frac{M_i^2 I_i + M_s^2 I_s}{M_o^2}$$

$$\frac{M_i^1 I_i}{M_o^1} + \frac{M_s^1 I_s}{M_o^1} = \frac{M_i^2 I_i}{M_o^2} + \frac{M_s^2 I_s}{M_o^2}$$

$$\frac{M_s^1 I_s}{M_o^1} - \frac{M_s^2 I_s}{M_o^2} = \frac{M_i^2 I_i}{M_o^2} - \frac{M_i^1 I_i}{M_o^1}$$

$$I_s \left(M_s^1/M_o^1 - M_s^2/M_o^2 \right) = I_i \left(M_i^2/M_o^2 - M_i^1/M_o^1 \right)$$

$$I_s = \frac{I_i \left(M_i^2/M_o^2 - M_i^1/M_o^1 \right)}{M_s^1/M_o^1 - M_s^2/M_o^2}$$

APPENDIX TABLE 1. Feeding levels of steers (experiment 1)

GROUP	FEEDING LEVEL (TIMES Estimated MAINTENANCE)	FEEDING LEVEL (kg/day, AS FED)
I	1.0	4.31
II	1.3	5.77
III	1.6	7.03
IV	2.0	8.39

APPENDIX TABLE 2. Ingredients of ration (experiment 1)

INGREDIENT	% AS FED
Pelleted alfalfa (Medicago sativa)	50.0
Rolled barley (Hordeum vulgare)	49.4
Salt, trace mineralized	0.5
Vitamin	0.1
	100.0

APPENDIX TABLE 3. Calculated composition of ration (experiment 1)

Digestible energy	11.63 MJ/kg
Crude protein	12.4 %
Calcium	0.6 %
Phosphorus	0.26 %
Vitamin A (premix)	1,980,000 I.U./kg
Vitamin D (premix)	300,000 I.U./kg
Vitamin E (premix)	1,980 I.U./kg

APPENDIX TABLE 4. Formula of concentrate mixture for bulls (experiment 2)

INGREDIENT	% OF MIXTURE
Oats (Avena sativa)	45.0
Barley (Hordeum vulgare)	42.1
Rapeseed meal (Brassica rapus)	6.0
Molasses (Wet)	4.0
Urea	0.4
Dicalcium phosphate	1.4
Trace mineralized salt	1.0
Vitamin premix*	0.1

*vitamin premix contains (per kg)

2,045,000 I.U. Vit. A

204,500 I.U. Vit. D

20,450 I.U. Vit. E

The ration to February 18 consisted of 40% of the above concentrates in pelleted form and 60% hammered (3.8 cm screen) hay. Subsequently it was 50% of each.

APPENDIX TABLE 5. Body weights and feeding levels of steers (experiment 3)

STEER	BODY WEIGHT (kg)	FEED/DAY (kg)
217	545	8.2
335	439	6.6
337	545	8.2
609	448	6.7

APPENDIX TABLE 6. Mean weekly temperatures (average of minimum and maximum, C) of the environments of outside and inside steers (experiment 1)

WEEK BEGINNING		OUTSIDE	INSIDE
Oct. 15	1975	5.7	15.2
Oct. 22		-1.3	15.2
Oct. 29		1.9	15.2
Nov. 5		1.8	13.5
Nov. 12		3.8	12.4
Nov. 19		-7.9	12.6
Nov. 26		-13.8	12.9
Dec. 3		-10.1	15.5*
Dec. 10		-28.7	11.5*
Dec. 17		-22.7	14.4*
Dec. 24		-2.4	15.2*
Dec. 31		-17.8	15.0
Jan. 7	1976	-21.8	11.8
Jan. 14		-7.4	14.0
Jan. 21		-7.0	16.4
Jan. 28		-0.4	16.5
Feb. 4		-9.5	12.1
Feb. 11		-10.5	17.0
Feb. 18		-6.1	18.1
Feb. 25		-15.8	18.6
Mar. 3		-10.5	19.5
Mar. 10		-7.9	19.3
Mar. 17		0.5	19.7

* values are means of 1300 h temperatures

APPENDIX TABLE 7. Hair depths (cm) of steers (experiment 1)

CONDITIONS	HOUSING	FEED LEVEL (TIMES MAINTENANCE)	SITE OF MEASUREMENT 1	2	3	4	5	6	7	8
Compressed	Inside	1.0	.35	.25	.35	.35	.35	.30	.25	.35
		1.3	.55	.45	.30	.35	.45	.35	.45	.40
		1.6	.40	.45	.30	.45	.45	.25	.25	.30
		2.0	.30	.35	.25	.30	.40	.30	.25	.20
	Outside	1.0	.45	.55	.75	.50	.55	.60	.50	.50
		1.3	.40	.45	.60	.45	.40	.70	.45	.40
		1.6	.30	.55	.50	.60	.35	.65	.50	.60
		2.0	.65	.45	.35	.45	.50	.40	.25	.50
Free Standing	Inside	1.0	1.15	1.25	1.85	1.50	1.50	1.75	1.45	2.00
		1.3	1.00	0.95	1.15	0.95	1.25	1.50	1.15	1.35
		1.6	1.05	1.25	0.85	0.80	1.00	0.75	1.65	1.35
		2.0	0.95	0.65	0.65	0.75	0.90	0.55	0.65	0.75
	Outside	1.0	1.70	2.15	3.00	1.25	1.90	2.00	2.30	2.50
		1.3	1.55	1.25	2.25	1.90	1.70	2.25	1.90	1.95
		1.6	1.00	1.70	2.75	1.35	1.25	2.40	1.65	2.20
		2.0	1.75	1.45	1.30	1.30	2.00	1.65	1.10	2.00

n=2
sites 1, 2, 3 : left side over hook bone, last rib and sepula respectively
4, 5, 6 : right side over hook bone, last rib and sepula respectively
7, 8 : on midline over mid-lumbar and mid-rib regions respectively

APPENDIX TABLE 8. Occurence of shivering and temperatures during observation of outside steers (experiment 1)

DATE	TEMPERATURE	NUMBER OF ANIMALS SHIVERING ACCORDING TO FEEDING LEVEL (TIMES MAINTENANCE)			
		1.0	1.3	1.6	2.0
Oct. 21 1975	9	0	0	0	0
22	9	0	0	0	0
23	5	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	2	0	0	0	0
Nov. 4	8	0	0	0	0
5	11	0	0	0	0
6	5	0	0	0	0
12	8	0	0	0	0
13	15	0	0	0	0
14	10	0	0	0	0
18	1	0	0	0	0
19	- 1	0	0	0	0
20	- 1	0	0	0	0
26	- 9	0	0	0	0
27	- 7	0	0	0	0
28	- 9	2	0	0	0
Dec. 2	- 9	1	0	0	0
9	- 3	0	0	0	0
10	-21	0	0	0	0
11	-23	0	0	0	0
16	-25	0	0	0	0
17	- 7	0	0	0	0
18	0	0	0	0	0
22	-11	0	0	0	0
23	- 2	0	0	0	0
24	- 1	0	0	0	0
29	0	0	0	0	0
30	- 7	0	0	0	0
31	-13	0	0	0	0
Jan. 6 1976	-28	4	3	3	1
7	-39	4	3	3	3
8	-25	4	3	3	3
9	-28	0	0	0	0
10	-15	0	0	0	0
13	-11	2	1	1	0
14	-15	0	0	0	0
15	- 2	0	0	0	0
16	- 2	0	0	0	0
27	5	0	0	0	0
28	3	0	0	0	0

APPENDIX TABLE 8 (Continued)

DATE	TEMPERATURE	NUMBER OF ANIMALS SHIVERING ACCORDING TO FEEDING LEVEL (TIMES MAINTENANCE)			
		1.0	1.3	1.6	2.0
Jan. 29 1976	5	0	0	0	0
30	- 2	0	0	0	0
Feb. 3	-10	0	0	0	0
4	-22	0	0	0	0
5	-12	0	0	0	0
6	- 7	0	0	0	0
10	- 2	0	0	0	0
11	0	0	0	0	0
12	- 5	0	0	0	0
17	- 5	0	0	0	0
18	- 9	0	0	0	0
19	- 2	0	0	0	0
21	-11	0	0	0	0
24	2	0	0	0	0
25	- 1	0	0	0	0
26	- 8	0	0	0	0
Mar. 2	-18	0	0	0	0
3	-30	0	0	0	0
4	- 9	0	0	0	0
5	-20	0	0	0	0
9	- 1	0	0	0	0
10	- 8	0	0	0	0
11	- 5	0	0	0	0
16	6	0	0	0	0
17	10	0	0	0	0
18	5	0	0	0	0
19	2	0	0	0	0
20	- 1	0	0	0	0
21	5	0	0	0	0
22	4	0	0	0	0
23	0	0	0	0	0
24	2	0	0	0	0
25	5	0	0	0	0

n=4 until January 20, subsequently n=2

APPENDIX TABLE 9. Respiratory rates and rectal temperatures of outside cattle (experiment 1)

DATE	AMBIENT TEMPERATURE (C)	RESPIRATORY FREQUENCY (respiration/min.)				RECTAL TEMPERATURE (C)			
		FEED LEVEL TIMES MAINTENANCE							
		1.0	1.3	1.6	2.0	1.0	1.3	1.6	2.0
Nov. 6 1975	5	----	----	----	----	39.6	39.3	39.5	39.3
13	15	----	----	----	----	38.9	39.1	39.2	39.3
Dec. 10	-21	----	----	----	----	----	----	----	----
17	- 7	----	----	----	----	38.6	38.9	39.0	39.0
23	- 2	25.0	18.5	27.5	35.0	39.1	38.8	39.0	39.0
30	- 7	13.0	18.5	20.5	25.5	38.7	38.7	38.8	38.7
Jan. 7 1976	-39	7.5	9.0	10.5	10.0	38.4	38.5	38.3	38.7
14	-15	10.0	9.5	12.0	11.5	38.5	38.5	38.7	38.7
28	3	12.0	20.0	29.0	23.0	38.8	38.9	39.1	38.7
Feb. 4	-22	----	----	----	----	39.0	39.0	38.8	38.7
5	-12	9.0	9.0	15.0	14.0	----	----	----	----
11	0	9.0	19.9	29.0	20.0	38.7	38.8	38.7	38.8
21	3	13.0	22.0	39.0	38.0	38.8	39.0	38.9	39.7
26	- 8	10.0	13.0	15.0	15.0	38.7	38.7	38.7	38.8
Mar. 3	-17	13.0	13.0	12.0	11.0	----	----	----	----
11	- 5	----	----	----	----	38.7	39.1	39.3	38.6

n=4 until Jan. 20, subsequently n=2

APPENDIX TABLE 10. Respiratory rates and rectal temperatures of outside cattle (experiment 1)

DATE	AMBIENT TEMPERATURE (C)	RESPIRATORY FREQUENCY (respiration/min.)				RECTAL TEMPERATURE (C)			
		FEED LEVEL TIMES MAINTENANCE							
		1.0	1.3	1.6	2.0	1.0	1.3	1.6	2.0
Nov. 6 1975	15	--	--	--	--	38.8	38.8	39.0	38.8
13	14	--	--	--	--	38.7	39.0	39.2	39.2
Dec. 17	12	--	--	--	--	38.6	39.1	39.0	38.0
23	15	27	24	41	23	38.6	38.8	39.0	38.8
30	15	25	22	35	35	38.6	38.5	39.0	38.7
Jan. 7 1976	11	16	19	22	32	38.6	38.7	39.0	38.8
14	10	21	24	34	38	38.5	38.5	38.7	39.0
28	16	27	30	36	34	38.9	39.0	38.9	39.0
Feb. 4	16	--	--	--	--	38.8	38.6	38.6	38.7
5	16	20	24	32	27	----	----	----	----
11	17	24	26	28	27	38.6	38.7	38.6	38.8
21	20	22	23	28	19	38.7	38.9	38.9	38.6
26	21	25	23	33	25	38.6	38.7	38.7	38.6
Mar. 3	19	19	23	22	22	----	----	----	----
11	18	--	--	--	--	38.4	38.5	38.8	38.9

n=2

APPENDIX TABLE 11. Estimates of shavings intake and digestibility for outside steers (experiment 1)

DATE		EFFECTIVE TEMPERATURE (C)	SHAVINGS INTAKE (kg/day)				DIGESTIBILITY (% D.M.)			
METHOD			AIA		Cr_2O_3		AIA		Cr_2O_3	
FEED LEVEL (TIMES MAINTENANCE)			1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
Nov.	12,13,14 1975	1.6	.55	.67	1.72	1.58	71.2	67.9	59.6	62.5
	26,27,28	- 8.8	.98	.97	----	----	72.3	72.7	----	----
Dec.	9,10,11	-10.9	1.95	1.20	1.68	.73	70.1	57.0	71.1	61.9
	22,23,24	-22.6	1.92	1.83	----	----	58.8	54.3	----	----
Jan.	6, 7, 8 1976	-20.8	1.61	1.79	1.29	1.26	60.3	65.7	63.4	64.9
	27,28,29	- 7.0	.49	.24	----	----	69.1	64.4	----	----
Feb.	10,11,12	- 9.2	.19	.05	.69	.85	70.6	71.3	64.2	63.3
	24,25,26	- 3.7	.98	.54	----	----	68.7	77.7	----	----
Mar.	9,10,11	-10.4	1.40	1.67	1.22	1.55	75.2	66.6	73.8	68.1
	16,17,18	- 8.0	.79	.82	1.13	1.51	73.7	70.3	70.5	63.5

n=2
AIA acid insoluble ash
Cr_2O_3 Chromium oxide

APPENDIX TABLE 12. Estimates of shavings intake and digestibility for inside steers (experiment 1)

DATE	EFFECTIVE TEMPERATURE (C)	SHAVINGS INTAKE (kg/day)				DIGESTIBILITY (% D.M.)			
METHOD		AIA		Cr_2O_3		AIA		Cr_2O_3	
FEED LEVEL (TIMES MAINTENANCE)		1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
Nov. 12,13,14 1975	13.5	.17	-.02	.20	.23	69.3	64.6	68.8	62.1
26,27,28	14.5	.64	.21	----	----	71.3	65.8	----	----
Dec. 9,10,11	13.0	.81	.49	.89	1.03	67.6	62.3	66.8	56.0
22,23,24	14.8	.84	.23	----	----	65.5	61.7	----	----
Jan. 6, 7, 8 1976	14.1	.71	.52	.42	.53	66.3	63.8	69.8	64.1
27,28,29	16.4	1.35	1.34	----	----	65.5	59.0	----	----
Feb. 10,11,12	16.6	.76	.90	.36	.65	60.0	65.2	65.9	67.6
24,25,26	18.6	1.82	1.55	----	----	72.8	70.9	----	----
Mar. 9,10,11	19.9	2.50	2.02	2.00	1.63	65.0	63.9	68.9	66.9
16,17,18	19.2	.84	.59	.33	.32	68.0	69.2	75.1	72.2

APPENDIX TABLE 13. Ruminating, lying, wet grooming and dry grooming behavior of steers (experiment 1)

DATE	HOUSING	FEED LEVEL (X MAINTENANCE)	TEMP. (C)	TIME AFTER SUNRISE (MIN.)	RUMINATING % TIME	LYING % TIME	WET GROOMING # - 10	DRY GROOMING # - 10
Jan. 9 1976	Outside	1.0	-28	12	37.5	95.0	0.00	0.00
		1.3			50.0	87.5	0.50	0.00
		1.6			50.0	75.0	0.50	0.38
		2.0			65.0	75.0	0.50	0.25
10	Outside	1.0	-15	13	27.5	50.0	0.50	2.25
		1.3			30.0	25.0	0.25	3.50
		1.6			42.5	45.0	0.50	0.75
		2.0			75.0	75.0	0.75	0.00
16	Outside	1.0	- 2	18	2.5	25.0	1.00	2.25
		1.3			12.5	32.5	0.50	1.50
		1.6			0.0	0.0	0.75	0.50
		2.0			0.0	40.0	0.75	1.25
30	Outside	1.0	- 2	36	10.0	0.0	1.00	0.00
		1.3			0.0	0.0	0.50	1.50
		1.6			0.0	0.0	0.00	0.50
		2.0			0.0	0.0	1.50	2.00
	Inside	1.0	16	60	10.0	0.0	1.00	1.00
		1.3			60.0	0.0	1.00	0.00
		1.6			25.0	0.0	3.00	0.00
		2.0			5.0	0.0	2.00	4.50
Feb. 6	Outside	1.0	- 7	50	0.0	0.0	2.00	2.50
		1.3			0.0	0.0	0.00	0.00
		1.6			0.0	0.0	3.50	0.00
		2.0			0.0	0.0	3.50	1.00
	Inside	1.0	14	60	40.0	50.0	0.50	1.00
		1.3			100.0	0.0	0.50	0.00
		1.6			50.0	0.0	1.50	1.00
		2.0			5.0	0.0	4.5	2.00

APPENDIX TABLE 13. Ruminating, lying, wet grooming and dry grooming behavior of steers (experiment 1) (continued)

DATE	HOUSING	FEED LEVEL (X MAINTENANCE)	TEMP. (C)	TIME AFTER SUNRISE (MIN.)	RUMINATING % TIME	LYING % TIME	WET GROOMING # - 10	DRY GROOMING # - 10
Feb. 21 1976	Outside	1.0	-11	72	0.0	50.0	1.50	0.00
		1.3			100.00	0.0	0.00	0.00
		1.6			55.0	100.0	1.00	0.00
		2.0			50.0	50.0	0.00	0.00
	Inside	1.0	20	72	25.0	0.0	1.50	2.00
		1.3			70.0	30.0	2.50	1.00
		1.6			40.0	20.0	1.50	1.00
		2.0			100.0	50.0	0.50	0.00
26	Outside	1.0	- 7	84	0.0	0.0	0.50	1.00
		1.3			0.0	0.0	0.00	0.50
		1.6			5.0	0.0	2.50	0.00
		2.0			0.0	0.0	1.00	2.00
	Inside	1.0	21	84	0.0	0.0	1.00	1.50
		1.3			50.0	0.0	1.00	0.50
		1.6			10.0	0.0	2.00	0.50
		2.0			0.0	0.0	4.50	1.50
Mar. 3	Outside	1.0	-30	108	60.0	50.0	1.00	0.00
		1.3			50.0	0.0	0.00	0.50
		1.6			55.0	0.0	0.00	0.00
		2.0			100.0	0.0	0.00	0.00
	Inside	1.0	19	108	25.0	50.0	1.50	0.00
		1.3			50.0	50.0	1.50	0.50
		1.6			70.0	50.0	2.50	0.00
		2.0			100.0	50.0	0.50	0.00
5	Outside	1.0	-20	113	45.0	0.0	1.00	1.00
		1.3			30.0	0.0	3.00	0.00
		1.6			50.0	0.0	0.50	1.00

APPENDIX TABLE 13. Ruminating, lying, wet grooming and dry grooming behavior of steers (experiment 1) (continued)

DATE	HOUSING	FEED LEVEL (X MAINTENANCE)	TEMP. (C)	TIME AFTER SUNRISE (MIN.)	RUMINATING % TIME	LYING % TIME	WET GROOMING # - 10	DRY GROOMING # - 10
Mar. 5 1976	Outside	2.0	-20	113	90.0	0.0	0.00	1.00
	Inside	1.0	19	113	0.0	0.0	3.00	2.50
		1.3			60.0	10.0	0.50	0.00
		1.6			70.0	40.0	0.00	1.50
		2.0			100.0	50.0	1.50	0.50

n=4 until January 20, subsequently n=2